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N2C2M2 Experimentation and Validation: Understanding Its C2 Approaches and Implications

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14. ABSTRACT

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Abstract

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INTRODUCTION

Information Age brought about new and powerful tools. In particular, the capability to exchange and process huge amounts of information in real-time between remote and distant parties has led to the development of new Command and Control (C2) approaches, such as Network Centric Operations (NCO) and Power-to-the-Edge principles (Alberts and Hayes 2003), being the latter characterized by broad distribution of information, unconstrained patterns of interaction and dynamic allocation of decision rights.
In fact, C2 capabilities have more to do with the largely unconsolidated theoretical framework that must lie beneath the way information domain is employed and used by individuals in order to generate the desired emergent behaviors in the cognitive and social domains, supporting the development of shared intent, shared awareness and understanding, which in turn leads to synchronized actions to achieve the desired effects. The definition of that theoretical framework represents a long way ahead and it is expected that experimentation will play a key role for its development and validation.
Notable recent work has been conducted in this field. C2 Conceptual Reference Models (C2 CRM) were developed by the CCRP ASD-NII/OFT (Alberts and Hayes 2006) and NATO SAS-050 (SAS-050 2006), providing useful and innovative insights towards the most important variables that characterize C2 processes and their interrelations. Another effort was taken by NATO SAS-065 to develop the NATO NEC C2 Maturity Model (N2C2M2) (SAS-065 2010), associating the ability to adopt one or more approaches to C2 with different levels of C2 maturity and describing its impact on numerous variables present in the C2 CRM.
This paper presents main findings of a recent effort undertaken to validate, through experimentation, the recently developed N2C2M2, while at the same time, understanding the implications of its C2 approaches, framed in terms of the NCW (Alberts *et. al.* 1999) (Alberts and Hayes 2006) and NATO (SAS-050 2006) (SAS-065 2010) conceptual frameworks.

This paper is organized as follows: it starts with a description of relevant Background in terms of theory (including fundamentals of NCW and the N2C2M2) and research (mainly, the ELICIT platform), then, in "Experiment Hypothesis and Early Expectations", it enumerates the hypothesis to test, the experimentation model (with explicit presentation of independent and dependent variables and their interrelations) and the experimental design, in "Experiments Analysis" it presents the analysis of the experiments and it finishes with the conclusions.
Given the large extent of this work, an Annex is included with this paper to present detailed information about the N2C2M2 experimentation, ELICIT platform and detailed data.

BACKGROUND

Most of this work's foundations are the fundamental aspects of Network-Centric Warfare (NCW) including the *NCW tenets*[1], *NCW Value Chain* (SAS-065 2010, 27), *C2 Domains* (Alberts and Hayes 2006), C2 CRM (SAS-050 2006) (Alberts and Hayes 2006) and *C2 Approach Space* (SAS-050 2006) (Alberts and Hayes 2006).
These foundations were used to define the experimentation model, key variables, their interrelations and design. A core aspect encompassing this work consisted in enabling the observation of several C2 CRM variables and their consequences as expressed by the *NCW Value Chain*, namely, observing how changing the way a force is networked (i.e., its C2 approach) affects (the quality of) shared information and collaboration, and in turn impacts shared situational awareness, shared understanding and mission effectiveness.

Recent experimentation efforts within the context of NCW and C2 approaches have been conducted through ELICIT, a research and experimentation programme developed for the CCRP, to better understand the issues of collaboration, information sharing and trust (see "Overview of the ELICIT Platform" in Annex and, for detailed information, (Ruddy 2007)). ELICIT includes a game-based software simulation platform that provides a network-centric collaborative environment for a small group or organization (constituted by humans and/or software agents), allows instantiation of different C2 approaches and enables observation of behaviors and dynamics in the information, cognitive and social domains due to its extensive and unobtrusive logging capabilities.

[1] Network Centric Warfare Department of Defense Report to Congress. July 2001.

ELICIT was originally developed to test hypothesis related with edge and hierarchical (traditional) command and control practices (Ruddy 2007) and its increased configuration capabilities and flexibility has enlarged its fields of application for research.
More specifically, the ELICIT web-version (webELICIT) (Ruddy 2008) will be used as a network-centric experimentation platform for this work since it provides easy manipulation and setup of organization models, control of communications, and, more importantly, a clear mapping with the theory of NCW, including a subset of the C2 CRM where several variables of interest are observable, including: *Quality of Individual and Shared Information Position, Information Distribution, Patterns of Interaction, Quality of Individual and Shared Understanding, Quality of Interactions, Self-Synchronization, Mission Effectiveness* and *Mission Efficiency (given Effectiveness)* (Manso and Nunes 2007) (McEver, Hayes and Martin 2007) (Martin and McEver 2008).

A preliminary experimentation effort, conducted within the aegis of NATO SAS-065, mapped ELICIT-Hierarchy model as an approximation of De-Conflicted C2 while ELICIT-Edge model to a region of the C2 approach space further along the central diagonal vector (toward Edge C2) allowing *testing the hypothesis that More Mature Levels of C2 would Perform More Efficiently and More Effectively*. Results were *clear and unambiguous* (SAS-065 2010, 132): Edge organizations were more effective, faster, shared more information and were more efficient than Hierarchies. Also based on empirical evidence, previous research work was also consistent with the hypothesis that Edge outperformed Hierarchies (Ruddy, 2007) (McEver, Hayes and Martin 2007) (Martin and McEver 2008). This work attempts to go further by recreating the N2C2M2 five C2 approaches in the ELICIT platform and observe its outcomes and main differentiating aspects.

Finally, we are fully aware of the ELICIT oversimplification towards application of C2 processes, nature of the problem (tame and well defined) and limitation on the collaboration level between subjects (e.g., fixed text share and post actions). These conditions only limit the extent to which ELICIT may validate the model.

The N2C2M2 is briefly introduced next.

The NATO NEC C2 Maturity Model (SAS-065 2010)
The N2C2M2 defines several degrees of operational coherence (the ability to generate synergies across a set of participants) that can be achieved. These are framed into the five levels of NATO NEC operational capability (levels 1 to 5). Associated with each level is the ability of the collective to adopt one or more approaches to C2. Moreover, associated with increased maturity is the ability to adopt a wider range of approaches to C2 that, in turn, cover a large portion of the C2 Approach Space.
The five classes of Collective C2 Approaches defined, representing a major differentiating aspect in each maturity level, are: Conflicted C2; De-conflicted C2; Coordinated C2; Collaborative C2; and Edge C2.
These approaches fit into specific regions of the Collective C2 approach space[2], as depicted in Figure 1.

[2] Note that the N2C2M2 deals with the set of entities engaged in a complex endeavour (Alberts and Hayes 2009, 4). Hence, the concept of C2 approach is interpreted in the perspective of a 'collective' (i.e., Collective C2). This implies re-interpretation of the dimensions of a Collective C2 approach space (SAS-065 2009, 2) as *allocation of decision rights to the collective* (ADR-C), *patterns of interaction among entities* (PI-C), and *distribution of information among entities* (DI-C).

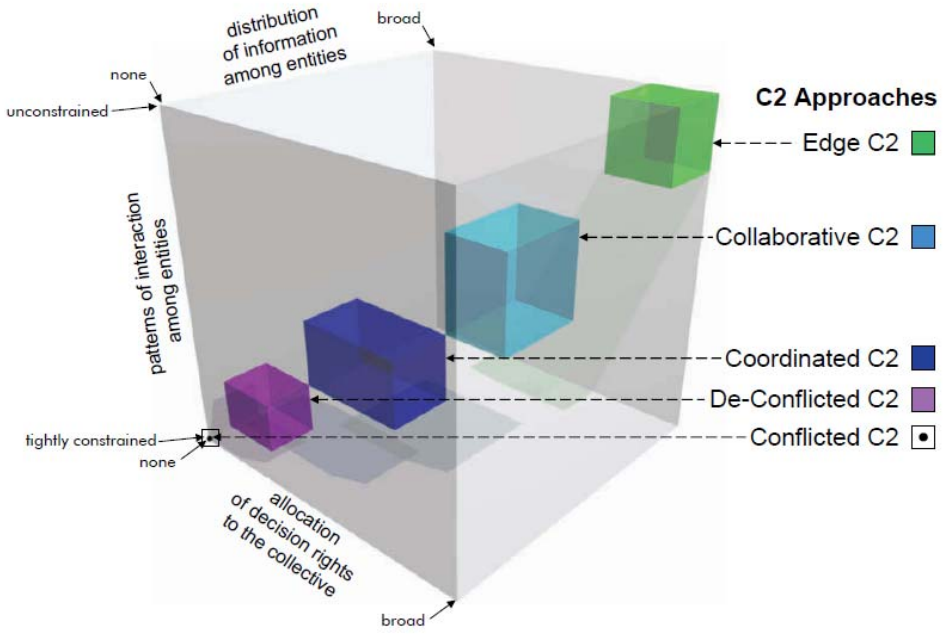


Figure 1 - Collective C2 Approach Space

Higher maturity levels include the ability to adopt C2 approaches located at the 'upper right' side of the C2 approach space (e.g., Collaborative and Edge). For convenience, approaches located at upper right corner will also be referred as more mature than those located at lower-left corner.

The qualitative value for each dimension, per C2 Approach, is presented in Table 1.

C2 key dimension / C2 Approach	ADR-C	PI-C	DI-C
Edge C2	Not Explicit, Self Allocated (Emergent, Tailored, and Dynamic)	Unlimited Sharing as Required	All Available and Relevant Information Accessible
Collaborative C2	Collaborative Process and Shared Plan	Significant Broad Sharing	Additional Information Across Collaborative Areas/Functions
Coordinated C2	Coordination Process and Linked Plans	Limited Focused Sharing	Additional information about coordinated Areas/Functions
De-conflicted C2	Establish Constraints	Very Limited Sharply Focused Sharing	Additional information about constraints and seams
Conflicted C2	None	No interactions across entities	Organic information.

Table 1 – Qualitative values for C2 Dimensions per Maturity Level

A main assumption in the N2C2M2 is: **more mature Collective C2 Approaches** (i.e., more distribution of decision rights across the collective, less constrained patterns of interaction and broader dissemination of information) **achieve higher levels of shared awareness and understanding which, in turn, result in increased endeavor effectiveness, efficiency** (given effectiveness) **and agility**.

This is summarized in Table 2 and it will support formulation of the main hypothesis for verification addressed in this work (see next section).

	Degree of Shared Awareness	Degree of Shared Understanding	Relative Effectiveness	Efficiency, Given Effectiveness	Agility of the Collective C2 Process
Edge C2	Broad, Deep, Tailored and Dynamic	Broad, Deep, Tailored and Dynamic	Tailored and dynamic synergies	Highly efficient	Proactive across a broad range of conditions
Collaborative C2	Significant	Significant	Substantial synergies across collaborative areas/functions	Substantial efficiencies across collaborative areas/functions	Substantial, timely and continuous
Coordinated C2	Limited	Limited	Limited synergies due to coordination	Limited efficiencies due to coordination	Limited to coordinated functions/actions; Slow; Reactive
De-conflicted C2	Focused on the boundaries	None	Avoids costs of negative cross-Impacts	Sub-optimized use of resources	Vulnerable at seams; Rigid from specialization
Conflicted C2	None	None	Negative cross-Impacts	Inefficiency wasted resources	Fragile and vulnerable at the seams

Table 2 – Results of C2 Approaches over MoM and MOFE

EXPERIMENT HYPOTHESIS AND EARLY EXPECTATIONS

The hypotheses for validation are:

[1] For a complex endeavor[3], higher collective C2 maturity approaches are more effective.

[2] For a given level of effectiveness, higher collective C2 maturity approaches are more efficient.

[3] Higher collective C2 maturity approaches are more agile.

Also relevant to measure and analyze in the same context are intermediate variables associated with the network centric value chain for they may provide important insights. The following hypotheses will also be tested:

Higher collective C2 maturity approaches exhibit increased/better levels of:

[4] Quality of Individual and Shared Information;

[5] Quality of Individual and Shared Awareness and Understanding;

[6] Self-Synchronization (at cognitive level);

Than: lower collective C2 maturity approaches.

Finally, it is expected a minimum level of maturity, that, if not met, an organization is not effective in the ELICIT game, i.e., *requisite maturity* (SAS-065 2010, 85) for the ELICIT game.

[7] Organizations require a minimum level of maturity to be effective in ELICIT.

[8] Increasing the degree of difficulty in ELICIT require organizations to increase their level of maturity to maintain effectiveness in ELICIT.

[3] It has been a matter of some debate if ELICIT presents a complex problem and if it achieves complexity at a systemic level. While the problem enunciated by ELICIT may be classified as simple or tame (i.e., is well defined and may be solved by elimination), the fact is that produced dynamics to reach a sufficient state of awareness (e.g., effective sharing of factoids across an organization) depend heavily on subjects behaviors and *will* and these are unpredictable and non-deterministic (hence complex). The fact is that, against expectations, more often than not subjects don't reach sufficient levels of distribution of information, awareness and understanding and, consequently, effectiveness in ELICIT is usually low (see SAS-065 2010).

Experimentation Model

The developed validation model for these experiments is depicted in Figure 2 and is an adaptation of the NCW value chain (Alberts and Hayes, 2003) and the ELICIT model (Alberts 2009) (SAS-065 2010, 219). This model includes the variables of interest and their key relationships.

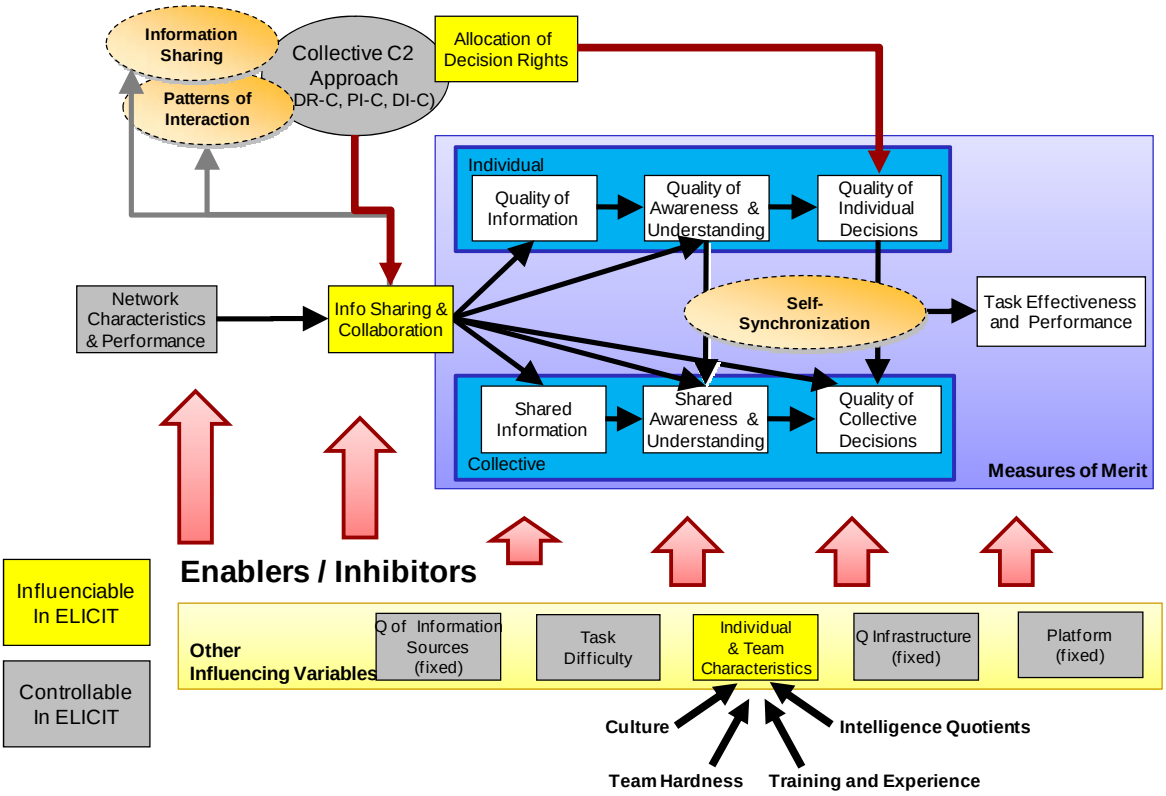


Figure 2 – N2C2M2 Model for Validation in ELICIT

The N2C2M2 key independent variable is *Collective C2 Approach*, which is expressed in terms of its three C2 key-dimensions variables: ADR-C, PI-C and DI-C (SAS-065 2010). The experimentation design will seek to influence and control these three variables, considering their highly dynamic nature, interrelations and dependency on humans' free *will* to interact and collaborate (note that ELICIT provides an interoperable infrastructure). Regarding this matter, we consider that, whenever humans are involved, *control* is not an accurate term and *influence* should be used instead. Hence, experiments are designed to provide (i) initial conditions to operate at a specific C2 Approach (e.g., network connectivity, network performance) and (ii) incentives to subjects so that adequate levels of performance (range intervals) are maintained, as characterized by the C2 Approach they should be operating at (e.g., allocation of decision rights and setting goals at team and organization level).

Details about manipulation of independent variables are provided in Table 3.

The model also includes the following variables of interest (intermediate dependent variables)[4]:

- Quality of Individual and Shared Information;
- Quality of Individual and Shared Awareness and Understanding;
- Quality of Individual and Shared Decisions; and
- Self-Synchronization.

The model dependent variable of interest is *Task Performance*, which measures individual, team and collective effectiveness and efficiency (given effectiveness).

[4] These variables are described in depth in available CCRP literature (e.g., (Alberts *et. al.* 2001) and (Alberts and Hayes 2006)) and NATO Publications (SAS-050 2006). The mapping between C2 variables and ELICIT was made in (Manso and Nunes 2008).

Moreover, relevant additional intervening variables, labeled as enablers/inhibitors, were identified with influence on the model. Their manipulation is out of the scope of this work, except for *Task Difficulty*. These variables are described in Table 16 in Annex.

Name	Description
Network Characteristics and Performance	Capabilities of the network as defined in terms of *reach*, *availability*, *bandwidth* and *responsiveness* (SAS-050 2006). *Reach* is controlled by allowing (or prohibiting) network interactions between subjects and teams. All others (*availability*, *bandwidth* and *responsiveness*) will be fixed for all experiments (ELICIT platform performance provides good availability, bandwidth and responsiveness). **This variable affects PI-C and DI-C**.
Information Sharing and (incentives for) Collaboration	This variable may be controlled and influenced: - Control: distribution of information by the ELICIT platform. All factoids are distributed and made available to subjects in three waves. - Influence: distribution of information as a result of human sharing and posting. Regardless of the infra/info-structure capabilities provided, it will be the subjects' *will* that will determine the extent of collaboration (how and if). We will attempt to induce / influence collaborative behavior by: - defining collective or isolated goals - set individual and collective decision rights (see **ADR**) See also Individual and Team Characteristics (in Annex). **This variable affects PI-C and DI-C**.
Allocation of Decision Rights	Decision rights will be allocated according to the C2 Approach to implement[5]: - Distributed for higher maturity approaches; - None / (de)centralized for lower maturity approaches. **This variable is a C2 dimension**.

Table 3 – Model independent variables

EXPERIMENT DESIGN

Using the ELICIT platform to observe various approaches to command and control that correspond to different level of C2 maturity described in the N2C2M2 requires modifying the ELICIT baseline organizational specifications (Ruddy 2007) (Ruddy 2008) as well as making modifications to the environment itself.
For the N2C2M2 experimentation, the scenario (terrorist attack) and nature of the problem is kept (i.e., determine *who*, *what*, *where* and *when*), as well as the factoids sets[6], organization size (17 subjects) and, when applicable, organization structure (i.e., three levels: overall coordinator, 4 teams each with 1 team leader and 3 team members). The information sharing capabilities are also maintained (i.e., share, post and pull actions) but, for higher maturity levels, factoids assessment is allowed as a way to enhance knowledge sharing between subjects. Moreover, interactions allowed between teams and subjects is now fully controlled as part of the ELICIT setup.

Table 4 provides an overall view of what is being manipulated in ELICIT to represent each of the N2C2M2 Collective C2 approaches. A detailed description of the experimental design is presented in "Detailed Design of Experiments" in Annex.

[5] Followed a similar approach adopted by (Chong *et. al.* 2007).
[6] Factoids sets were reused for these experiments, but were translated to Portuguese language. Moreover, reclassification in relevance was performed (see "Solution Logic" in Annex).

Independent Variables / Collective C2 Approach	Network Characteristics and Performance	(Incentives for) Information Sharing[7] and Collaboration (Initial conditions)	Allocation of Decision Rights to the Collective	Organizational Structure
Model 5: Edge	Fully connected and interoperable. Existing P2P connectivity between all individuals. Shared team websites.	Collective goals set to all individuals (no predefined roles) and unrestricted communications policies (across individuals with shared websites and factoids evaluation) should increase and enrich interactions and collaboration among all individuals.	Fully distributed / not explicit (per individual) and dynamic. Individuals choose which part (or parts) of the problem space they work.	1 team with 17 team members (non-hierarchical).
Model 4: Collaborative	Fully connected and interoperable. Existing P2P connectivity between all individuals. Shared team websites.	Collective goals set to Coordinator and Team leaders together with unrestricted communications policy (across individuals with shared websites and factoids evaluation) should increase and enrich interactions and collaboration among individuals (still with stronger ties expected between Coordinator and Team leaders).	Distributed and collaborative. Across Team leaders and coordinator/facilitator. Coordinator/facilitator works in all problems.	4 teams (with 1 team leader) and 1 Coordinator/Facilitator.
Model 3: Coordinated	Minimum connectivity. Stove-pipe: between Team leaders and coordinator. Teams exclusive access to their websites. Coordinator access to all websites.	Collective goals centralized by function (Coordinator, assisted by Team leaders) should enable stronger interactions among *hierarchies* and *subordinates* (Coordinator and Team leaders and Team leaders and Team members).	Centralized (in Coordinator). Team specialized problem space.	4 teams (with 1 team leader) and 1 Coordinator/Facilitator.
Model 2: De-conflicted	Minimum connectivity. Stove-pipe: between Team leaders and Information Broker. Teams exclusive access to their websites.	Isolated goals, but factoids interdependency should enable weak/minimum interactions, between stove-pipes (Deconflictor and Team leaders).	Established constraints (share what is relevant to other teams). Decision allocated to each Team leader. Team specialized problem space.	4 teams (with 1 team leader) and 1 information broker.
Model 1: Conflicted	Teams exclusive access to their website. Non-interoperable (no cross-teams communications).	None outside teams.	None (independent decision rights within teams only)	4 isolated teams a 1 isolated subject.

Table 4 – Five Organizational Models for Five C2 Approaches: in a Nutshell

Part of the incentive policies implemented is based on setting organization goals according to adopted approach, as presented in Table 5.

Collective C2 Approach	Criteria for Mission Effectiveness
Model 5: Edge	Set at Organization level (fully-distributed). Each member may work on any problem space and the most frequent ID (mode value) in each problem space must be correct.
Model 4: Collaborative	Set at Organization level (Coordinator and Team Leaders). Coordinator must determine the correct solution in all problem spaces OR Team Leader (assigned a problem space) must determine the correct solution for *his* problem space.
Model 3: Coordinated	Set at Organization level (centralized at Coordinator). Coordinator must determine the correct solution in all problem spaces.
Model 2: De-conflicted	Set at Team Level only. Each Team Leader is assigned a problem space and he must determine the correct solution to *his* problem space.
Model 1: Conflicted	Set at Team Level only. Each Team Leader is assigned a problem space and he must determine the correct solution to *his* problem space.

Table 5 –Mission Effectiveness criteria per C2 Approach

[7] The ELICIT platform distributes all factoids in three waves.

EXPERIMENTATION BASELINE

The experimentation baseline comprises collected data from runs, which includes ELICIT setup files, preparation material (Subject's instructions and ELICIT setup files), subjects' questionnaires and ELICIT logs (see "

Data Collection and Analysis Process" in Annex). The list of runs analyzed is presented in Table 6.

ID	Date	Log File	C2 Approach	Factoid Set
L1-01	13-05-2009	20090513-1053-21812-group_1_CONFLICTED.log	CONFLICTED	4
L1-02	28-05-2009	20090528-1246-32783-group_1_CONFLICTED.log	CONFLICTED	1
L1-03	03-06-2009	20090603-1135-40719-group_1_CONFLICTED.log	CONFLICTED	3
L2-01	29-04-2009	20090429-1308-24386-group_1_B.log	DECONFLICTED	1
L2-02	29-04-2009	20090429-1402-18407-group_1_B.log	DECONFLICTED	4
L2-03	12-05-2009	20090512-1511-12023-group_1_DECONFLICTED.log	DECONFLICTED	1
L2-04	02-06-2009	20090602-1413-19588-group_1_DECONFLICTED.log	DECONFLICTED	3
L3-01	07-05-2009	20090507-1413-26985-group_1_COORDINATED.log	COORDINATED	1
L3-02	13-05-2009	20090513-1142-59475-group_1_COORDINATED.log	COORDINATED	3
L3-03	03-06-2009	20090603-1212-12301-group_1_COORDINATED.log	COORDINATED	2
L3-04	03-06-2009	20090603-1332-06152-group_1_COORDINATED.log	COORDINATED	4
L4-01	06-05-2009	20090506-1133-24903-group_1_COLLABORATIVE.log	COLLABORATIVE	1
L4-02	06-05-2009	20090506-1225-19696-group_1_COLLABORATIVE.log	COLLABORATIVE	4
L4-03	12-05-2009	20090512-1415-19171-group_1_COLLABORATIVE.log	COLLABORATIVE	3
L4-04	02-06-2009	20090602-1515-03801-group_1_COLLABORATIVE.log	COLLABORATIVE	2
L5-01	29-04-2009	20090429-1101-06528-group_1_A.log	EDGE	1
L5-02	29-04-2009	20090429-1152-08894-group_1_A.log	EDGE	4
L5-03	07-05-2009	20090507-1500-37261-group_1_EDGE.log	EDGE	4

Table 6 – N2C2M2 experiment runs

About 4 valid runs were conducted per C2 approach, covering all factoids sets available[8]. However, the following faults occurred: for level 2, factoid set 1 was used twice and factoid set 2 was not used; for level 5, only 3 valid runs[9] were conducted, factoids set 4 was used twice and factoids set 2 and 3 were not used.
Collected data allowed identifying differentiating aspects between each C2 approach, but we are aware that more data (hence, more runs) are necessary to conduct a robust statistical analysis and to consolidate findings.

The experiments analysis is presented in next section.

EXPERIMENTS ANALYSIS

For the experiments analysis, several C2 variables are measured so that approaches may be objectively characterized and compared. In essence, we intend to identify quantitative and qualitative aspects differentiating the C2 approaches.

The following is measured:

- Information Domain: **level of information accessible**, level of **overall shared information reach** and level of **information reached for key roles** (CTC and team leaders)[10]. Finally, awards are given based on information scores with *timestamp* (indicating when score was achieved).
- Interactions and Social Domain: **nature, quantity and quality of the interactions** (number of shares, posts and pulls actions per subject, team and overall organization), **network reach** and **deviation of *inward* and *outward* flows from the mean**.
- Cognitive Domain: **correct understanding (extent of)** for overall and each problem space and a measure of **self-synchronization** (labeled as *Cognitive Self-Synchronization*). Awards are given based on extent of understanding scores with *timestamp*.
- Measures of Merit: **effectiveness** and **efficiency** (in time and cost).

[8] Trial runs, which preceded runs for analysis, were not included in table.
[9] An EDGE run was invalidated because recorded logging contained inconsistencies between setup and actual organization approach.
[10] It should be noted that:
- Overall shared information reach is the set of information which may be reached by all subjects, and
- Information reached is the set of information which has been reached by a subject (i.e., information is considered accessed when a share is received or a pull is performed).

Data measurements will be presented for all runs and/or approaches. Presentation of mean values will include reference to maximum and minimum values[11]. Most tables and charts used should be self-explainable, except for statistical charts and mean deviation chart which are briefly explained in Annex.

Information Domain

All new factoids are distributed by server in 3 waves[12] (see Table 3, *Information Sharing* row). By default, waves 1, 2 and 3 occur at 0, 5 and 10 minutes respectively. However, due to a misconfiguration, some runs used the following setup: wave 1 @ 0 minutes, wave 2 @ 1 minute and wave 3 @ 2 minutes. Affected runs were: L1-03, L3-03, L3-04 and L4-04. This modification will be considered when analyzing the experiments.

All information (68 factoids) becomes accessible after wave 3. Figure 3 presents increase in information accessibility across time.

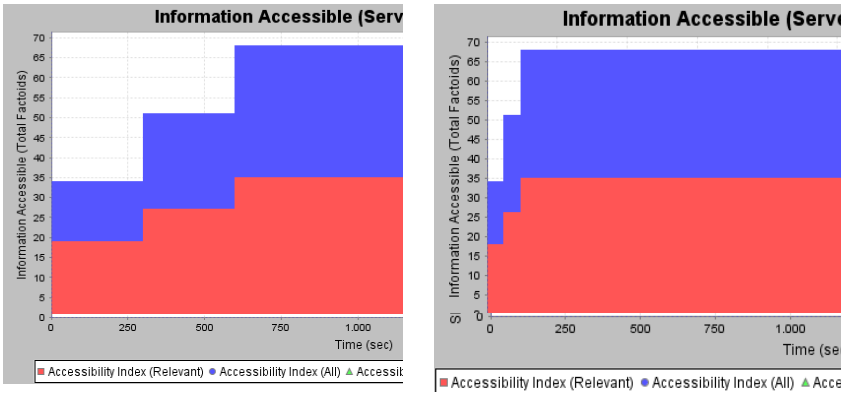


Figure 3 – Information Accessibility across time: default (left) and changed (right) modifications

The server distribution of factoids to subject is further depicted in Figure 4. It is clear that factoids are uniquely distributed to subjects. Note that colors represent factoids relevance (Green=K/E, Orange=S, Grey=N).

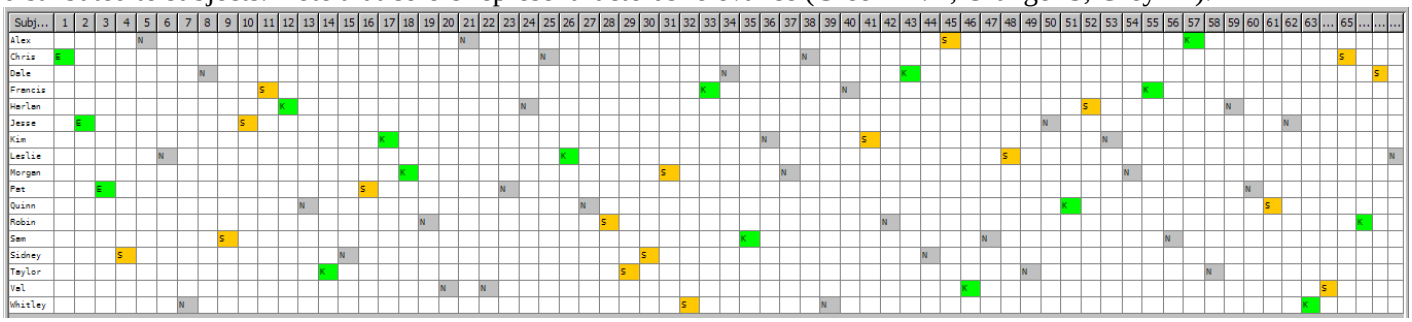


Figure 4 – Server Distribution of Factoids to Subjects

As a result of share and post actions, factoids become accessible to more subjects and, therefore, individual and shared information reach increases. An example is presented in Figure 5.

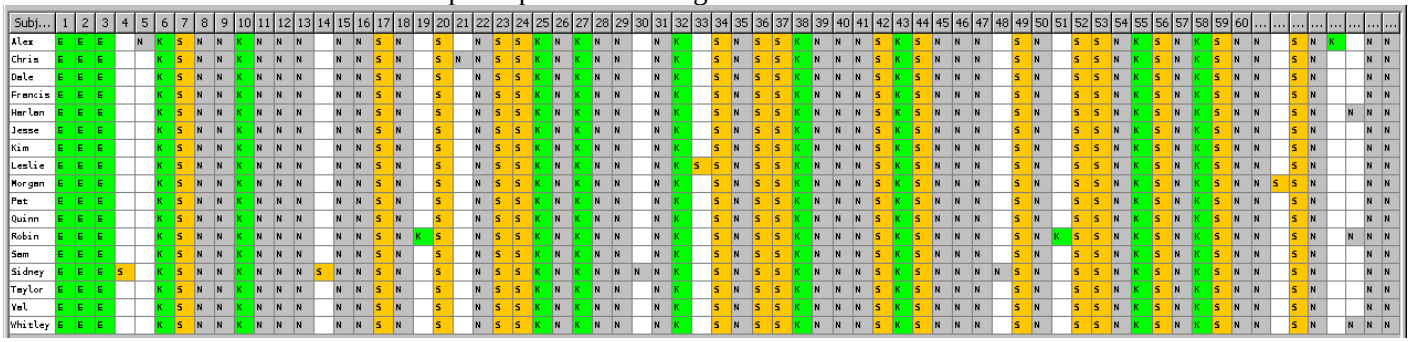


Figure 5 – Factoids Distribution to Subjects after shares and posts actions (Edge run L5-02)

[11] Standard deviation will not be used since few data is available.

[12] Each factoid set has 64 factoids. For all experiments, platform is setup to disseminate factoids as follows: wave 1 sends 32 factoids, wave 2 sends 17 factoids and wave 3 sends 17 factoids (all factoids are made available to subjects after wave 3). Each wave distributes about the same proportion of relevant and noise factoids. Platform is setup so that factoids are first disseminated to only one subject (i.e., sharing of information between any two subjects as a result of factoids server distribution is always zero). See also (Ruddy 2007).

The amount, extent and speed of information shared are strongly influenced by the organizational approach used. Figure 6 presents scores[13] achieved in key variables of the information domain across C2 approaches.

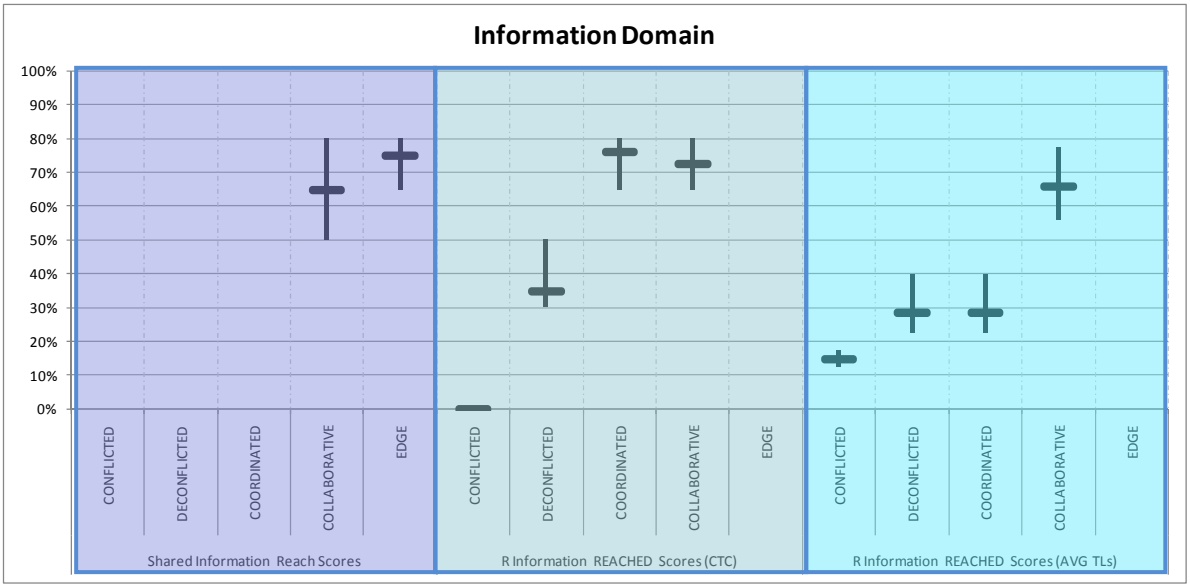


Figure 6 – Scores in the Information Domain

Shared Information Reach was measured as the set of information (i.e., factoids) which is accessible to all subjects. Only COLLABORATIVE and EDGE approaches obtained values other than zero: COLLABORATIVE obtained an average value of 65% (ranging between 50% and 80%) while EDGE obtained the best overall score with an average value of 75% (ranging between 65% and 80%). Both organizations were very effective sharing information, but none reached 100%, meaning that local hoarding of factoids occurred.

Given zero scores for CONFLICTED, DECONFLITED and COORDINATED, individual measurements are therefore necessary to assess performance in distribution of information for these approaches (COLLABORATIVE is also included for completeness, while role analysis is not applicable for EDGE). For these approaches, measurements will focus on key roles, namely, the overall coordinator (CTC, a.k.a. ALEX)[14] and team leaders.

Relevant Information Reached was measured as percentage of relevant information (i.e., K, E or S factoids) actually accessed (received after a share or after pull) by a subject. Value for CONFLICTED was zero (since CTC is isolated, he can only reach the 4 factoids sent by server), then increased to 35% (min: 30%, max: 50%) in DECONFLICTED, COORDINATED had maximum overall score with 76% (min: 65%, max: 80%) and COLLABORATIVE had a similar score with 73% (min: 65%, max: 80%). In fact, the result obtained by the COORDINATED approach is interesting for, although *overall shared information reach* score is zero, the organization was very effective in sharing information to their centralized decision maker. Note also that CTC is the main responsible for zero score in information sharing in DE-CONFLICTED and COORDINATED (see organizations' setup in Annex), meaning that subjects playing this role behaved as information aggregators and hoarders.

Average (value of) Relevant Information Reached by Team Leaders was also measured to evaluate each of the approaches' ability to disseminate information across teams and to key roles. The following can be concluded:

- Except for CONFLICTED (EDGE being not applicable), results obtained in all other approaches were always inferior to those obtained for the CTC. This indicates that subjects having the overall coordinator role usually (i) hoard some information from team leaders or (ii) team leaders don't reach information which was made available to them. The highest difference in value was observed for COORDINATED approach in which team leaders reached an average value of 29% (min: 23%, max: 40%) while CTC reached an average of 76%.
- Only COLLABORATIVE achieved above average scores (>50%), while both DECONFLICTED and COORDINATED remained below 30% (CONFLICTED was limited to about 10%). All these approaches failed in making information available across teams.

[13] Scores were awarded when values reached 10%, 20%, 30%, 50%, 65%, 80% and 100% of total.
[14] More precisely, isolated coordinator for CONFLICTED, information-broker for DECONFLICTED, cross-team coordinator (CTC) for COORDINATED and CTC/facilitator for COLLABORATIVE. This role is always played by subject named by ELICIT as ALEX. For simplicity, this role will be referred as CTC.

Illustrative examples are provided in ANNEX 'Information Reach and Information Reached by Subjects'. The following is outlined:

- Both EDGE and COLLABORATIVE were very efficient disseminating information across the organization, but local hoarding always existed. Table 19 and Table 20 (top part) illustrate two EDGE runs were most information is shared: the former included hoarding of 3 K/E facts (and few S and N) while the later succeeded in having all K/E within reach of all Subjects. Likewise, two COLLABORATIVE runs are illustrated in Table 21 and Table 22: in the former a few factoids are hoarded (including K/E) while in the later more critical information was shared across organization. Yet, observing results for information reached provides further interesting insight on subjects' behavior: although most subjects were *information seekers* (see "Interactions and Social Domain" section), a few didn't reach all accessible information (as a result of no shares or no sufficient pull actions on websites). This is illustrated in bottom part of Table 21 and Table 22. Illustrative and extreme examples for EDGE and COLLABORATIVE are provided in Table 20 (bottom part) by Jesse and Table 22 (bottom part) by Harlan (Table 17 presents Information Domain Score detailed data).
- COORDINATED approaches were very efficient disseminating information to CTC, but not to overall organization. Table 23 illustrates a run where almost all key factoids were effectively made available to ALEX, except 55K, which provided critical information about WHEN-day (interesting, this factoid was shared between WHERE team members but not to the WHERE team leader). Moreover, information was heavily partitioned to teams. Table 23 also illustrates a particular case where there is no shared information between any two teams.
- DECONFLICTED approaches had a decrease in shared information for Information Broker (ALEX) and Team Leaders. As illustrated by Table 24, it is interesting to note the impact of changing roles on subjects' sharing behavior (this aspect is further analyzed in "Interactions and Social Domain" section): Team Leaders had the main role in this organization: the extent of information shared to ALEX was less than in COORDINATED (some information was retained within teams)
- CONFLITED is presented here for completeness. Table 25 illustrates partition of information across teams and isolated coordinator, which couldn't be shared across teams due to setup connectivity restrictions.

An essential aspect was to measure the ability to share critical information to key positions (the right information in the right position). Critical information was considered as the minimum subset of factoids required to determine a problem space (see "Solution Logic" in Annex), according to following criterion:

- CTC needs critical information for all problem spaces
- TL and TMs needs critical information for their problem space.
- In EDGE, all TMs need critical information for all problem spaces.

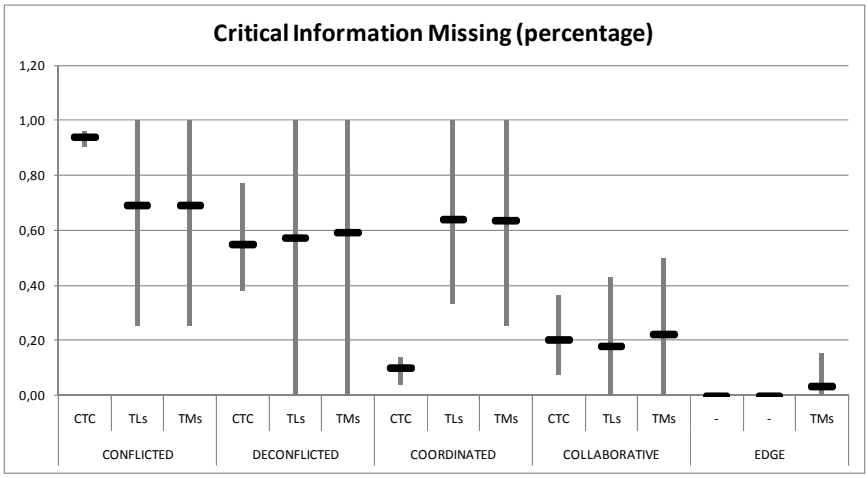


Figure 7 - Percentage of Critical Information Missing

Variable measured was **Percentage of Critical Information Missing** (per approach and per role) presented in Figure 7. As maturity increases, percentage of critical information missing in key-roles decreases. EDGE reaches the lowest score with a low variation between extremes, COLLABORATIVE succeeded making critical information across roles (although variation increased as role position decreased). The change between COORDINATED and DECONFLICTED approaches illustrates the heavy asymmetry between CTC and TLs already mentioned here. The scale is, nevertheless, impressive: CTC decreased from 10% to 55% information missing, while TLs variation remained relatively stable (with an increase between min-max variation from L3 to L2). As expected, CONFLICTED had the highest percentage of critical information missing.

An assessment on the approaches performance in the information domain, according to information scores and time efficiency, yield the results detailed in Table 7.

		Information Domain: L1 to L3 RELEVANT Information Reached (CTC) L4 to L5: Shared Information (accessible) (OVERALL)						
Run ID	LEVEL	10%	20%	30%	40%	65%	80%	100%
L1-01	L1							
L1-02	L1							
L1-03	L1							
L2-01	L2	313	621	1110				
L2-02	L2	143	340	582	1057			
L2-03	L2	110	387	757				
L2-04*	L2	106	396	748	1748			
L3-01	L3	42	98	265	420	665	1805	
L3-02	L3	19	37	80	324	600	680	
L3-03*	L3	36	91	113	202	304	1420	
L3-04*	L3	57	107	162	390	878	1432	
L4-01	L4	38	112	329	514	1351		
L4-02	L4	27	39	58	321	523	702	
L4-03	L4	123	293	338	622			
L4-04*	L4	43	78	113	162	234		
L5-01	L5	64	95	320	627	2219		
L5-02	L5	38	62	97	360	659	1304	
L5-03	L5	94	142	208	530	652	1172	

* Early delivery of factoids from server as illustrated in Figure 3

Table 7 – Information Domain Scores

For **shared information accessible**, the best overall scores were obtained by EDGE approaches. 2 out of 3 runs reach a score of 80% (at 1172 and 1304 seconds). However, COLLABORATIVE had the best efficiency: 80%@702 seconds. 2 out of 4 runs obtained 65%, one reached very early (234 seconds), as a consequence of subjects' shares and posts and early distribution of factoids (see Figure 3 right part).

Since the other three approaches didn't achieve minimum score of 10% for **shared information accessible**, their assessment individual scores were awarded based on the percentage of the **relevant information reached** by CTC[15].

All 4 COORDINATED runs achieved a score of 80%, of which L3-02 had, exceptionally, a good efficiency (680 seconds). Moreover, in this approach, Team Leaders usually achieve a low score of 20% (see Table 18 in Annex).

DECONFLICTED runs achieved 40% and 30% scores for CTC, demonstrating that the amount of information kept within each team reach was substantial. Again, the data provided by Table 18 (in Annex) displays a slight improvement in information accessed by Team Leaders, which, at most, reached 50%.

CONFLICTED didn't reach minimum scores for ALEX while Team Leaders reached between 10% and 20% of the information (see Table 18).

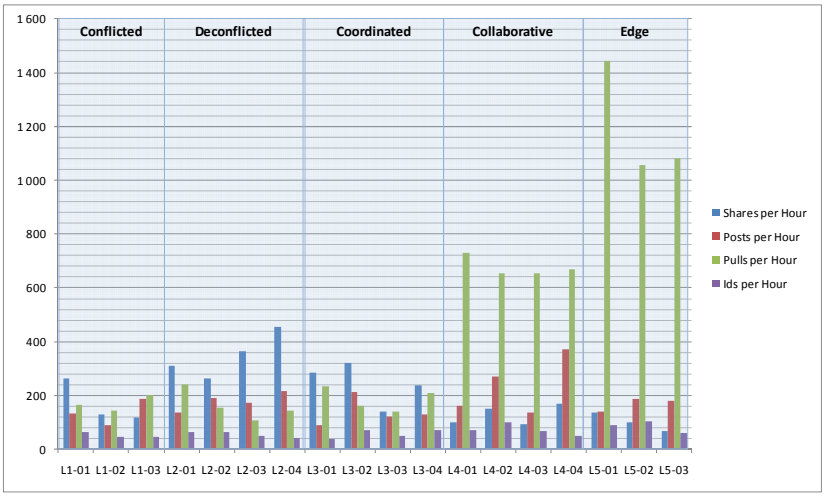
Finally, the change in the periodic delivery of server factoids had not a significant effect (see L2-04, L3-03, L3-04), except for L4-04 run (took less time to reach a high score).

Interactions and Social Domain

Interactions in ELICIT consist of all subjects' shares, posts and pulls actions. Depending on the approach, their number, frequency, distribution and reach may change.

We start by analyzing the number of actions per hour (since duration of runs is not exactly the same). The results are presented in Figure 8 (detailed data is presented in Table 26 and Table 27).

[15] Assessment of CTC scores intended to evaluate his pro-activity to seek information (hence REACHED) and quality of data achieved (hence RELEVANT).



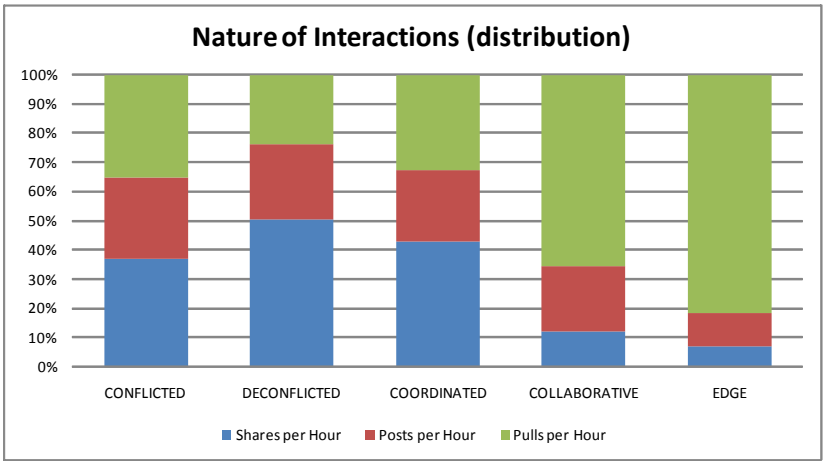


Figure 8 – Nature of Interactions: totals per hour (top) and distribution (bottom) per approach

There are clear differences between the five approaches.

- Number of pulls per hour reached its highest values for EDGE approaches (maximum value was 1443 for L5-01). EDGE Subjects were *information seekers*. COLLABORATIVE approach followed with second highest values (about half of EDGE). All other approaches had few pulls per hour (ranging from 109 to 242).
- Number of posts per hour reached its highest value for COLLABORATIVE approaches (maximum value was 372 for L4-04), followed by all other approaches with no significant differences.
- Number of shares per hour reached its highest value for DECONFLICTED approach (maximum value was 455 for L2-04), followed by COORDINATED. These two approaches required sharing to pass information across teams, but DECONFLICTED clearly performed more shares (from CTC to TLs). Both EDGE and COLLABORATIVE had the lowest sharing activity.
- Number of IDs per hour reached its highest value for EDGE, followed by COLLABORATIVE.

Both COLLABORATIVE and, especially, EDGE had intensive pull activity (see Figure 8, green bar) representing 66% and 82% (of share, post and pull) respectively. Key-factors may have been the availability of all websites to all subjects and the instructions to induce collaboration and sharing. Moreover, EDGE subjects had yet another factor enabling individual pro-activity towards *information seeking* which was distribution of decision rights (i.e., each subject identification was relevant to determine organization effectiveness).

DECONFLICTED and COORDINATED approaches required *share* actions to share information across teams. Therefore, it is not surprising that shares activity was higher than those observed for COLLABORATIVE or EDGE. Another interesting aspect was to observe a decrease in sharing activity between DECONFLICTED and COORDINATED, likely to be a consequence of changing role from Information Broker (share intensive role) to a centralized approach (propensity to receive shares from team leaders but not send shares to team leaders).

The aspect of role influence in subjects' behavior and related asymmetries may be better understood by measuring subjects deviation in terms of *outflows* (OUT: shares sent and posts, i.e., distribute information) and *inflows* (IN: shares received and pulls, i.e., receive and/or seek information) from normal (or average) behavior.
That is, for a given subject S_i :

$$IN\_DEV_{S_i} = (nbr\_shares\_received_{S_i} + nbr\_pulls_{S_i}) - (Average\_nbr\_shares\_received + Average\_nbr\_pulls)$$

$$OUT\_DEV_{S_i} = (nbr\_shares\_sent_{S_i} + nbr\_posts_{S_i}) - (Average\_nbr\_shares\_sent + Average\_nbr\_posts)$$

Deviation in terms of IN and OUT behavior is expressed in absolute terms, allowing to interpret its true proportions.

The average values and standard deviations per role (i.e., CTC, TL and TM) and per approach were calculated[16]. Figure 9 illustrates the resulting values, discriminated per approach and per role. The chart needs explanation for proper interpretation, provided in "Explanation of IN and OUT Flows Chart" in Annex.

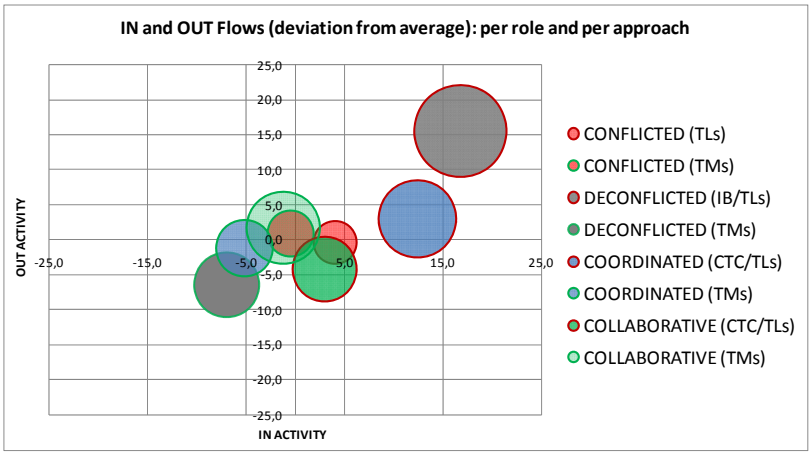


Figure 9 – IN and OUT Flows per role and per approach

IN propensity: all coordinator and leader roles displayed a higher deviation for IN propensity (all red circumferences are located on the right size). Highest value occurred for DECONFLICTED, followed by COORDINATED. Leader roles' IN propensity in CONFLICTED and COLLABORATIVE were positive but close to average. Team members always had a negative deviation for IN propensity in all four approaches.
OUT propensity: Leader role in DECONFLICTED showed a significant OUT positive deviation, followed by COORDINATED: such is consistent with organizational need for leaders to disseminate information across teams. Team member roles were close to average, except in DECONFLICTED, which was below average.

Figure 27 (last column) presents node balance (IN and OUT activity) per approach for a particular run. It is interesting to note the following particular cases:

- CTC had a major deviation from L2 to L3: significant decrease in OUT and significant increase in IN given its change from *Information Broker* (sharer) to Coordinator (information aggregator). TLs also had a significant deviation from L2 to L3: decrease in IN and OUT.
- TMs IN and OUT activity in L2 and L3 had a low deviation from normal behavior (small role relevance). Deviation increased for L4 and L5 (higher role relevance). TMs may have perceived an increase in relevance as maturity with increased maturity.

Noted asymmetries are consistent with expectations: excluding CONFLICTED (which only considers interactions within teams), on average, behavioral asymmetries between leader roles and member roles decrease as the maturity approach increases.
Finally, subjects' IN and OUT *natural propensity* should not be ignored when dealing with role assignment. The values obtained for standard deviation (see Table 29) indicate a high variation from the mean. Therefore, although general patterns were noted, subjects behaved differently at individual level (perhaps influenced by their own personality and social traits) and, therefore, not always as adequately as the *job* required.

Another relevant measure consists of the network reach, measured as the percentage of the network that each node (or subject) reached or was reached by, i.e., *sent to* or *received from* share actions. The following variables were measured: maximum, average and minimum (per run and per approach). Peer-to-peer (p2p) indicators for network inclusion and network exclusion were obtained by counting the number of nodes with more than 50% (7 or more subjects reached which means high *network inclusion*) and less than 10% (less than 1 subject reached meaning high *network exclusion*) network reach. This analysis only considered direct peer-to-peer actions (i.e., *share*) and didn't consider any *post* activity. Results are presented in Table 8 and overall chart is presented in Figure 10.

[16] The calculations kept their original units so that true proportions can be assessed across different approaches. The detailed values, per run, are presented in Table 29 in Annex.

EDGE approach obtained the highest network P2P reach (71% for L5-03) and maximum average value (57%), followed by COLLABORATIVE.

Both EDGE and COLLABORATIVE also obtained highest *network exclusion*. For example, it is surprising to note that EDGE run L5-03 had 14 nodes that reached less than 10% of the network.

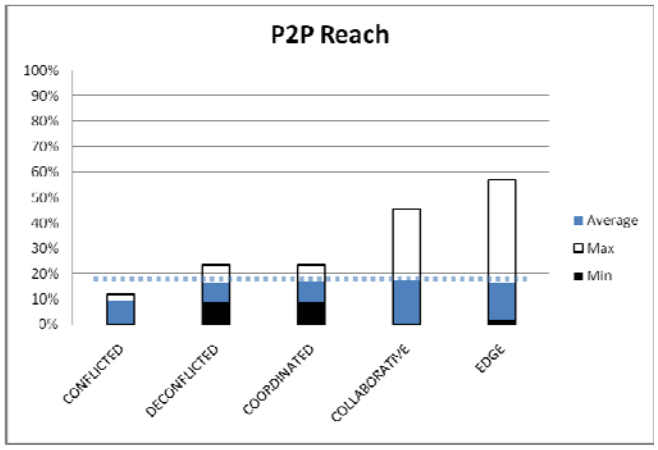


Figure 10 – P2P Network Reach

Run ID	Average	Min	Max	Nbr < 10 %	Nbr > 50 %
L1-01	15%	0%	18%	2	0
L1-02	13%	0%	18%	3	0
L1-03	15%	0%	18	1	0
L2-01	18%	12%	24%	0	0
L2-02	13%	6%	24%	6	0
L2-03	16%	6%	24%	3	0
L2-04*	17%	12%	24%	0	0
L3-01	18%	12%	24%	0	0
L3-02	17%	6%	24%	3	0
L3-03*	15%	6%	24%	2	0
L3-04*	19%	12%	24%	0	0
L4-01	17%	0%	41%	6	0
L4-02	21%	0%	59%	5	**1**
L4-03	20%	0%	47%	4	0
L4-04*	13%	0%	35%	**8**	0
L5-01	26%	6%	65%	4	**2**
L5-02	14%	0%	35%	**8**	0
L5-03	9%	0%	71%	**14**	**1**

Table 8 – Network Reach Values

Network reach for levels 3 and below were limited by ELICIT setup, but average values were closer to maximum allowed (24% for CTC and TLs and 18% for TMs).

Some relevant considerations may be raised:

- Availability of all websites (for EDGE and COLLABORATIVE) may have contributed to less P2P interactions. Websites are in fact efficient mechanisms to share information, replacing need of shares. An interesting aspect to further analyze is the effect (positive or negative) of technologies w.r.t. mediating (or replacing) interpersonal interactions.
- Moreover, EDGE registered a higher value for *network exclusion* than COLLABORATIVE, meaning that moving from an ordered structure (teams and team roles) to a flat one may also reduce P2P interactions: in COLLABORATIVE, subjects were given instructions to support other members, but in EDGE they weren't.
- Another interesting aspect arises when analyzing the average network reach for each approach: all approaches, except CONFLICTED, have a value close to 17%. Clearly, there is a gap between potential and true reach of network, which tends to increase with network size. Moreover, what is the average network reach for humans?

More data and research is required to properly address these considerations.

The final metric obtained to characterize and evaluate interactions in ELICIT is the **Quality of Interactions (QI)**, which was measured using following arithmetic function as follows:

$$Q_{Interactions} = \sum R\_factoids_{shared\_and\_posted} - \sum N\_factoids_{shared\_and\_posted}$$

QI is positive if more relevant factoids are shared and posted than non-relevant ones and negative otherwise. Note that quantity matters when obtaining QI. Results are presented in Figure 11 (detailed values are presented in Table 30 in Annex).

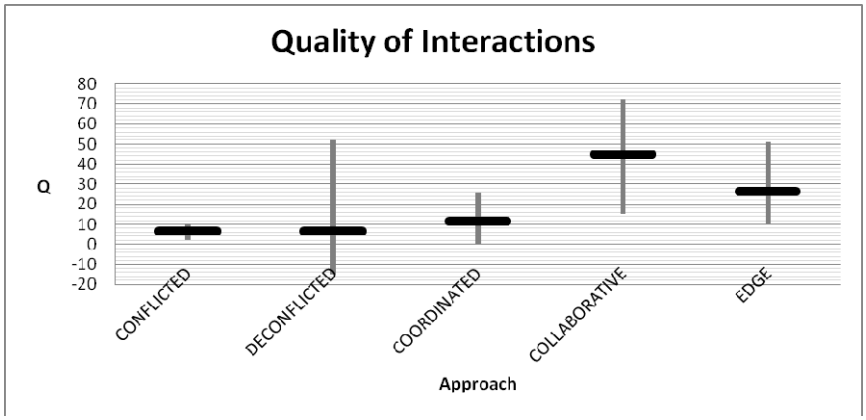


Figure 11 – Quality of Interactions

COLLABORATIVE was the most successful approach filtering and distributing relevant information over non-relevant information, obtaining highest QI value (45, with a high min-max variation), followed by EDGE (27). All other three approaches achieved low scores. DECONFLICTED had a wide min-max variation (from -15 to 52).

QI increases as maturity approach increases until COLLABORATIVE and decreases in EDGE.

Cognitive Domain

The cognitive domain deals with subjects' awareness and understanding of problem. Its complex processes occur within subjects' brain, but its outcomes may be measured when an identification attempt is performed.
A key variable is **extent of correct understanding**, which measures the number of correct identifications in each problem space (i.e., *who, what, where* and *when*). The overall results per approach are presented in Figure 12 and Figure 13 further details score per problem space. Detailed data is presented in Table 34).

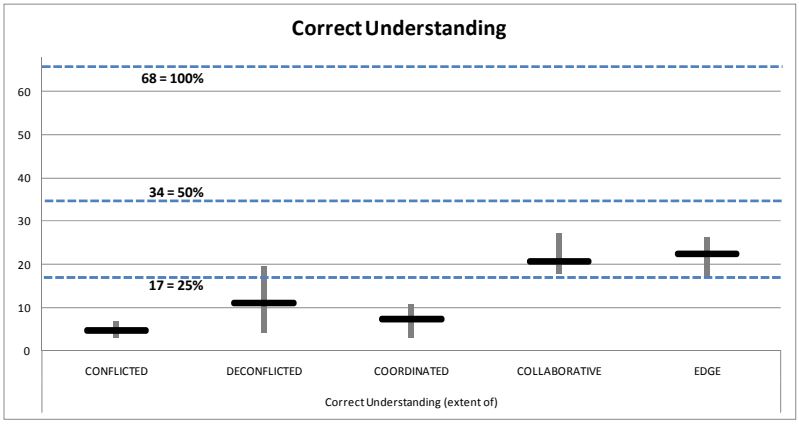


Figure 12 – Extent of Correct Understanding

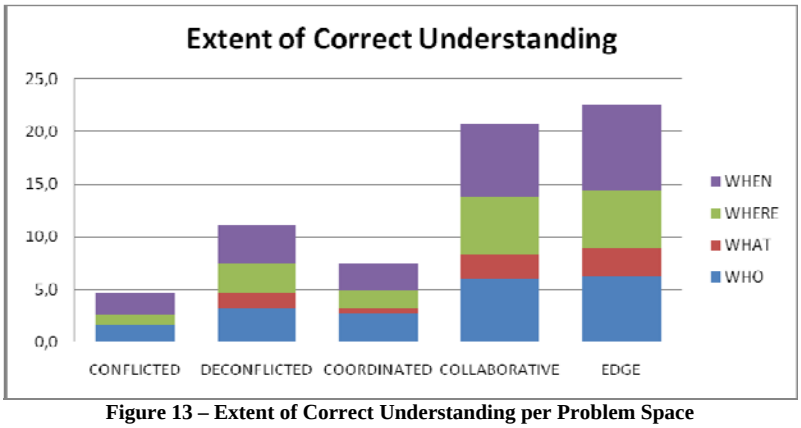


Figure 13 – Extent of Correct Understanding per Problem Space

Run ID	LEVEL	Extent of Correct Shared Understanding						
		10%	20%	30%	50%	60%	80%	100%
L1-01	L1							
L1-02	L1							
L1-03	L1							
L2-01	L2							
L2-02	L2							
L2-03	L2	**1028**	**1618**					
L2-04	L2	2120	2212					
L3-01	L3							
L3-02	L3	**1509**						
L3-03	L3	2058						
L3-04	L3	1840						
L4-01	L4	1874	2107					
L4-02	L4	**1353**	**1760**	**2010**				
L4-03	L4	1831	2331					
L4-04	L4	1361	1880					
L5-01	L5	1053	1892					
L5-02	L5	**977**	**1101**	**1258**				
L5-03	L5	1472	1583	1705				

Table 9 - Extent of Correct Shared Understanding Scores

In overall, extent of correct understanding was low (always below 30%). EDGE obtained the overall best score (22.6 correct answers), closely followed by COLLABORATIVE (20.8 correct answers).
Somewhat surprising was the low value obtained for COORDINATED (7.5 correct answers). It seems its centralized nature degraded overall extent of correct understanding, being surpassed by DECONFLICTED (11.2 correct answers, although with a large min-max range).
CONFLITED results are consistent with the model: it obtained the worst scores (on average, only 4.7 correct answers).

Extent of correct understanding was further decomposed per problem space, providing further evidence toward assessing an approach effectiveness across in each space. Results are illustrated in Figure 13. The findings are consistent across all approaches: in terms of success rate, WHO and WHEN had the highest scores (easiest to solve) and WHAT had the lowest scores (most difficult to solve).
Moreover, scores for the **extent of correct understanding** were awarded to each run with *timestamp* (indicating when score was achieved). Results are provided in Table 9. Only COLLABORATIVE and EDGE reach 30% scores, being EDGE always faster (30%@1258 seconds for L4-02). Most COLLABORATIVE runs only reached 20%. COORDINATED never reached more than 10% scores, DECONFLICTED did better with 2 runs at 20% and CONFLICITED never reached minimum score.

The last variable used to assess C2 approaches in the cognitive domain is a measure of **self-synchronization,** labeled as *Cognitive Self-Synchronization*.

The method used to measure this variable was inspired by Moffat's work towards developing a knowledge metric (Moffat 2003) to measure the amount of uncertainty in a probability distribution (based on Shannon's Information Entropy).

Cognitive Self-Synchronization (CSSync) will measure the amount of disorder (or entropy) of an organization towards determining the problem (i.e., finding *who*, *what*, *where* and *when*). Note that whether the solution is correct or wrong is not relevant here. Translating subjects' identifications as a measure of uncertainty, the function we will use to represent CSSync is the following:

$$\text{CSSync}_{problemSpace} = 1 - \sum_{i=1}^{N} P(S_i) * \ln(P(S_i)) / Max\_Disorder_{problemSpace}$$

CSSync is measured for each identification input field[17] (or *ProblemSpace*), namely, *who*, *what*, *where*, *when* (further decomposed into *when-time*, *when-day* and *when-month*), in which:

- *N* refers to total number of unique identifications (in the corresponding *ProblemSpace*).
- $P(S_i)$ is the proportion of a given identification S_i relative to organization size (size is equal to 17, i.e., the total number of subjects in ELICIT). Note that $0 < P \leq 1$.
- $Max\_Disorder_{ProblemSpace}$ refers to maximum entropy value (described below) and is used to normalize value (between 0 and -1).

Addition of 1 is done so that $CSSync \in [0,1]$. The value is interpreted as follows:

- CSSync=0 means system is fully disordered.
- CSSync=1 means system is fully synchronized.

We assume that any organization operating in ELICIT has an initial state of maximum disorder (maximum entropy), that is:

$P(S) = \frac{1}{N}$ (since all *N* subjects have different understandings, there are *N* possible outcomes each with equal probability or proportion, where *N*=17) and, therefore, $Max\_Disorder_{problemSpace} = -\sum_{i=1}^{N} \frac{1}{N} * \ln(\frac{1}{N}) = \ln(N)$.

The measure for the overall organizational CSSync is simplified to be the sum of the partial $\text{CSSync}_{ProblemSpace}$ that is:

$$CSSync = 0.25 * \sum_{i=problemSpace} CSSync_i \qquad \text{(weights are used to normalize total CSSync)}$$

As game progresses, subjects make identification attempts and it is expected that some of these attempts are equivalent. In such scenario, the cognitive disorder decreases (or, the cognitive order increases) and the organization is said to be converging to a common understanding of the problem. Ultimately, if all subjects provide the same identifications, we may conclude that the system was able to fully self-synchronize and converge. In such scenario:

$P(S_{problemSpace}) = 1$ for all *ProblemSpace*, (all subjects have the same understanding of the problem) and, therefore, $CSSync = 1$.

Note also that, if subjects don't perform an identification attempt, disorder is assumed.

Figure 14 presents the overall results for *CSSync* across the C2 approaches (for detailed data see Table 32 and Table 33 in Annex).

A first conclusion is that cognitive disorder decreases as the maturity increases:

- CONFLICTED is the most disordered state (with low variation from average),
- DECONFLICTED and COORDINATED have similar mean values, but the former presents a larger variation from the average value than the later.
- EDGE reached most synchronized state (0.42 for L5-01) and overall best. This finding is strengthened by the small min-max range variation.
- COLLABORATIVE second best synchronized state (0.34) but with a min-max variation (between 0.22 and 0.42).

[17] In ELICIT, Subjects enter identification attempts in free forms for the following fields: who, what, where, when-time, when-day, when-month.

It is interesting to note that, although both EDGE and COLLABORATIVE provided same access to information and subjects, the degree of cognitive self-synchronization achieved was lower for the later. The fact that in COLLABORATIVE there was an assignment of roles (i.e., CTC, team leaders and team members) may have induced less pro-activity in team members to work toward finding the solution while, on the other hand, adoption of *power-to-the-edge* principles (Alberts and Hayes 2003) in EDGE may have increased members' pro-activity to work towards finding the solution resulting in an increase in overall (cognitive) self-synchronization.

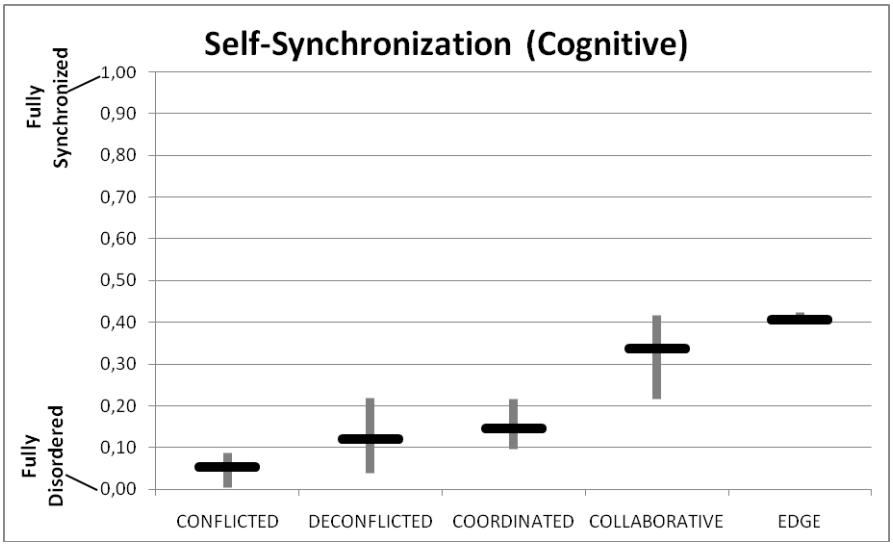


Figure 14 –Cognitive Self-Synchronization (Cognitive)

Charts displaying the evolution of CSSync through time are presented in Figure 28 in Annex. A remarkable finding is observing the early disorder decrease in EDGE run L5-02 (0.25@1250sec) while, for all other approaches, this occurs at late stages of the experiment.

Measures of Merit

Assessment of approaches is made with basis on the following Measures of Merit (Alberts and Hayes 2002):

- Measures of Force Effectiveness (MoFE): will measure organization effectiveness with basis on the criteria defined in Table 5.
- Measures of Performance (MoP): will measure efficiency given effectiveness in two dimensions:
  - Measure of time (e.g., how fast) to reach a given effectiveness level.
  - Measure of effort (e.g., transactions costs) to reach a given effectiveness level.

Organization Effectiveness (MoFE) is determined according to effectiveness criteria described in Table 5. Since there are 4 problem spaces, the following formula is used:

$Effectiveness = \sum_i 0.25 * Correct\_ans_i$, in which:

- *i* is the index of each problem space.
- If i=*who*, *what* and *where*: $Correct\_ans_i$ is 1.0 if correct answer is provided and 0.0 otherwise.
- If i=*when*: $Correct\_ans_{when} = 0.34 * Correct\_ans_{when\_time} + 0.33 * Correct\_ans_{when\_day} + 0.33 * Correct - ans_{when\_month}$

Overall scores are presented in Figure 15 (detailed data is provided in Table 35 in Annex).

COLLABORATIVE approach had best (100%) and overall best score (80%), EDGE was the second best (61%). COORDINATED (with 34%) was again surpassed by DECONFLICTED (44%) and CONFLICTED had worst score (31%).

In fact, the COORDINATED approach is an interesting case to analyze further. Although Coordinator (CTC) had most information available, he didn't, for most runs, provide a correct solution. Furthermore, in run L3-01, CTC didn't performed any ID (0 score was given as a consequence), in L3-02 and L3-03 scores were low (0.25 and 0.17 respectively), but L3-04 achieved a high score of 92%. Effectiveness in a COORDINATED approach is highly dependent on the performance of the coordinator.

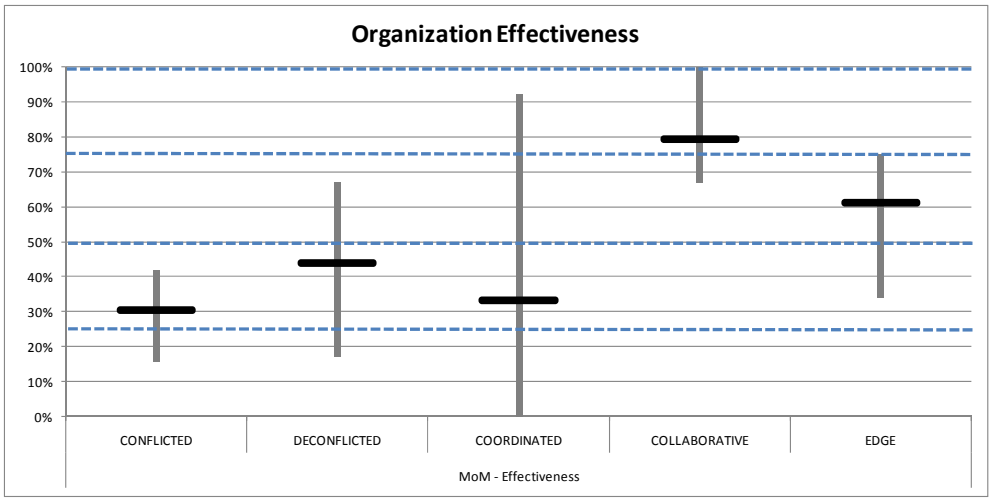


Figure 15 – Organization Effectiveness

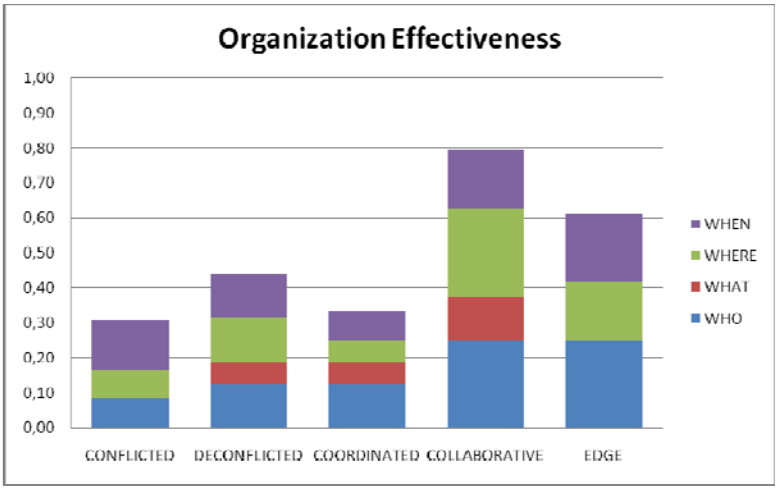


Figure 16 – Organization Effectiveness per solution space

Another surprising result was the effectiveness decrease from COLLABORATIVE to EDGE. Three main factors are speculated to contribute to this result:

1. Non-task specialization (i.e., all subjects work in all spaces) makes problem more difficult. On the other hand, COLLABORATIVE set teams assigned to tasks (i.e., solve a problem space) with positive results.
2. Information overload: after an EDGE run, several subjects (but not all) complained about having too much information to process.
3. Organizational effectiveness criteria: the criteria used for EDGE was clearly the most demanding (the answer considered was the *mode* value taken from the subjects answers set in each problem space) and it never was achieved when composite answers were required (typical in WHAT). For example, L5-02 and L5-03 used factoid set 4, in which correct answer for *what* is 'SECULAR SCHOOL', but most subjects answered 'SCHOOL' resulting in failure. As illustrated in Figure 16, no EDGE run succeeded finding a correct *what*. Also, conducting two runs with factoid set 4 may have introduced some bias in the effectiveness results.

Organization efficiency (MoP) is determined to assess organization performance in terms of time efficiency (given effective) and effort spend. Two variables are used: time-efficiency and effort-efficiency.

To calculate time-efficiency, the following formula was used:

$$Efficiency_{time} = Effectiveness\_score^2 * \log_{10}(1 + {}^{1}\!/_{time\_last\_ID})$$

The formula awards higher values for organizations which are more effective and faster reaching the last correct identification and penalize those which are less effective and slower. Figure 17 presents the results per run (left) and mean values per approach (right) in a normalized scale (0-1). Data for calculations was extracted from Table 35.

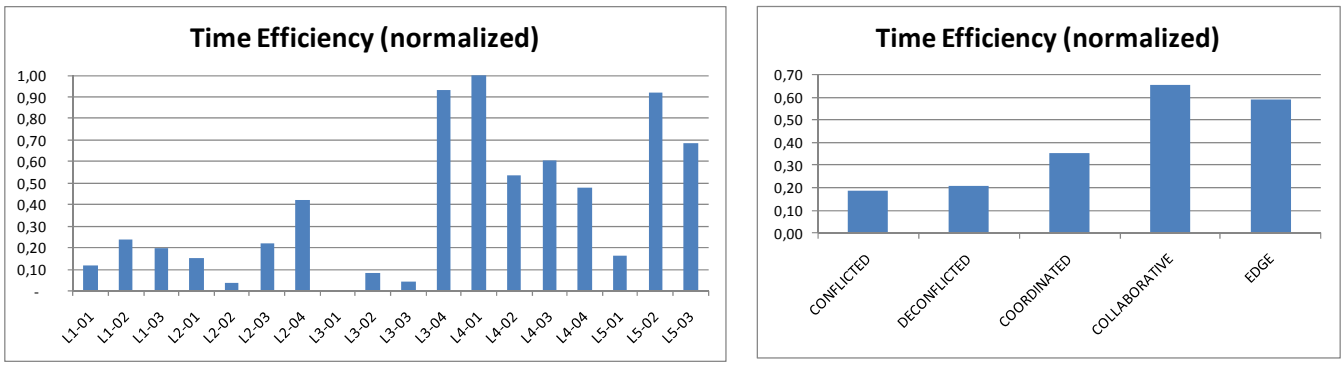


Figure 17 – Time Efficiency: per run (left) and per approach (right)

In general, increasing the maturity approach results in a time-efficiency increase (with a slight decrease from COLLABORATIVE to EDGE). Yet, results obtained were irregular across runs:

- Most time-efficient run was L4-01 (COLLABORATIVE) and second best was L3-04 (COORDINATED). Two EDGE runs followed (L5-02 and L5-03).
- COORDINATED had three runs with extremely low time-efficiency (L3-01 being the lowest). It should be also mentioned the low score of EDGE run L5-01 (with low effectiveness score).

To calculate effort-efficiency, the following formula was used:

$$Efficiency_{effort} = Effectiveness\_score^2 * \log_{10}(1 + {}^{1}\!/_{effort\_spent})$$

effort spent accounts all transactions costs occurring in a ELICIT run, in which a *share*, *post*, *pull* or *identification* action is considered to have a (unitary) transaction cost.
The formula awards higher values for organizations which are more effective and spend less (i.e., less transactions) during the run and penalize those which are less effective and spend more (i.e., more transactions).
Figure 17 presents the results per run (left) and mean values per approach (right) in a normalized scale (0-1). Data for calculations was extracted from Table 35 (effectiveness score) and Table 26 (effort). Additionally, Figure 29 in annex presents the average value of effort spent per approach: clearly, EDGE spent more effort than any other approach (more than 400 units than COLLABORATIVE, the second more expensive), while CONFLICTED spent less. Also interesting was having COORDINATED as second less expensive approach.

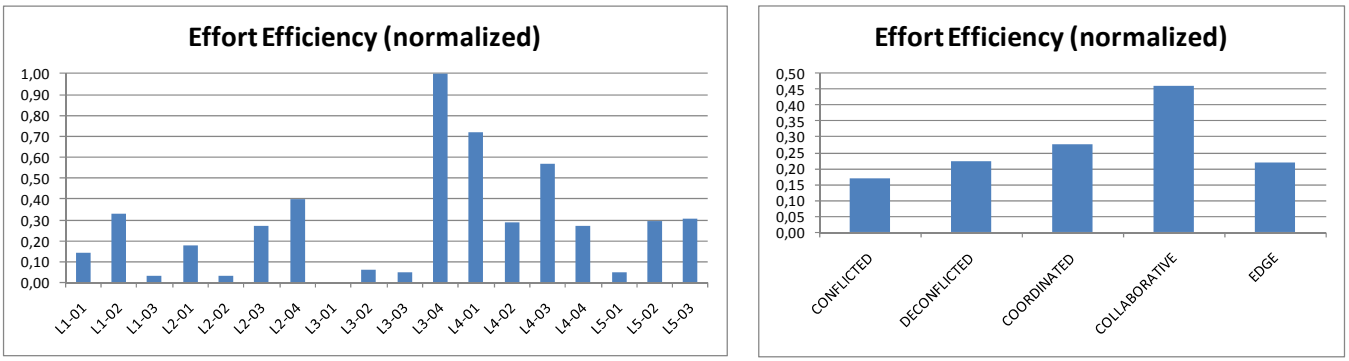


Figure 18 – Effort Efficiency: per run (left) and per approach (right)

In general, increasing the maturity approach results in a effort-efficiency increase, except when moving from COLLABORATIVE to EDGE, in which a significant decrease was observed (less efficient than COORDINATED and as inefficient as DECONFLICTED). Yet, results obtained were irregular across runs:

- Most effort-efficient run was L3-04 (COORDINATED) and second best was L4-01 (COLLABORATIVE) followed by L4-03.
- Ironically, it was L3-01, a COORDINATED run, which achieved lowest effort-efficiency. In fact, all other COORDINATED runs had low scores.

The low effort-efficiency obtained for EDGE is justified by the large effort spent by this approach, mainly due to the massive use of *pulls*. However, there should be caution interpreting effort-efficiency considering current experiments' setup: no indication of cost to deduct any organizational goals was provided in subject's instructions and, therefore, it was not a concern for subjects to *save* actions.

CONCLUSIONS

The validation of the N2C2M2 resorting to the ELICIT platform and a set of experiments specifically designed to model each approach level yielded interesting results and enabled a deeper understanding of maturity model approaches and related assumptions (or hypothesis). This work also focused on measuring key variables so that a quantitative analysis could be conducted.

The overall assessment of C2 approaches, according to the results obtained in the ELICIT experiments, is presented in Table 10. C2 approaches are evaluated in a 1-5 scale: 1 refers to best score and 5 refers to worst score. Grey background indicates non-compliance with model hypothesis.

Domain / Variable Assessed \ C2 Approach		CONFLICTED	DECONFLICTED	COORDINATED	COLLABORATIVE	EDGE
Information Domain	Shared Information Reach	**5**	4	3	2	**1**
	Critical Information Accessible	**5**	4	3	2	**1**
Interactions	Quality of Interactions	**5**	4	3	**1**	2
Cognitive Domain	Extent of Correct Understanding	**5**	3	4	2	**1**
	Cognitive Self-Synchronization	**5**	4	3	2	**1**
MoM	Organization Effectiveness	**5**	3	4	**1**	2
	Time-Efficiency	**5**	4	3	**1**	2
	Effort-Efficiency	**5**	3	2	**1**	3

Table 10 – Overall Position of C2 Approaches across assessed variables

In overall, the results are consistent with model expectations, but some deviations are observed especially regarding some assessment scores between EDGE and COLLABORATIVE and COORDINATED and DECONFLICTED.
We start by analyzing these results together with verification of hypothesis [4], [5] and [6], which focused on the model intermediate variables (Figure 2).

[4] *Higher collective C2 maturity approaches exhibit increased/better levels of* ***Quality of Individual and Shared Information*** *than lower collective C2 maturity approaches.*

Results obtained for all approaches were consistent with this hypothesis. More specifically, regarding shared information reach across organization, only EDGE and COLLABORATIVE achieved non-zero scores (with high levels). Relevant information reached for key-roles (i.e., CTC and TLs) was therefore measured and it was observed that COORDINATED obtained high levels for CTC but low levels for TLs, meaning coordinator didn't effectively shared information with its 'subordinates'. Relevant information reached decreased for DECONFLICTED (steep decrease for CTC) and reached a minimum at CONFLICTED.
An aspect worth to note is that no organization reached 100% of information shared. In fact, local hoarding of critical information across runs and approaches was common (such behavior is inconsistent, for example, with COLLABORATIVE and EDGE approaches).
While EDGE approaches were the more effective (and efficient) distributing information, best efficiency score was achieve by COLLABORATIVE (L4-02) and, regarding individual reach (CTC), COORDINATED (L3-02).

[5] *Higher collective C2 maturity approaches exhibit increased/better levels of* ***Quality of Individual and Shared Awareness and Understanding*** *than lower collective C2 maturity approaches.*

Results obtained for all approaches, except COORDINATED, were consistent with this hypothesis. We confirmed that levels of Individual and Shared Awareness and Understanding increased from CONFLICTED (lowest value), to

DECONFLICTED, COLLABORATIVE and EDGE. However, COORDINATED approach had lower values than for DECONFLICTED. As noted before, the COORDINATED approach empowers a centralized node (CTC), hence concentrates power and knowledge, with negative influence on situation understanding for all other nodes. The fact that DECONFLICTED sets independent decision making in each team, hence distributing cognitive goals and efforts, may explain the third best score.

[6] *Higher collective C2 maturity approaches exhibit increased/better levels of* ***Self-Synchronization (at cognitive level)*** *than lower collective C2 maturity approaches.*

Results obtained for all approaches were consistent with this hypothesis. An aspect to note was the high value obtained for EDGE and small min-max variation. Moreover, EDGE was also the fastest approach to self-synchronize.

[1] *For a complex endeavor, higher collective C2 maturity approaches are more effective.*

Results obtained were consistent with this hypothesis for all approaches except COORDINATED and EDGE. COLLABORATIVE was the most effective approach, followed by EDGE. EDGE approach was particular sensitive to WHERE problem (no correct solution was ever found at organization level). Moreover, DECONFLICTED achieved better scores than COORDINATED. The later was particularly irregular, for overall results were mediocre (below 0.25), except for L3-04 that was almost 100% effective. In fact, CTCs had always access to information necessary to solve one or more parts of the problem, meaning conditions to succeed were present, but not having *the right* subject assigned to the CTC role resulted in failure. We consider this analogy valid to real organizations that adopt COORDINATED approaches, i.e., organizational success is heavily dependent on a single person's judgments and decisions, and ability to remain adequate to a wide range of circumstances and complex endeavors.

[2] *For a given level of effectiveness, higher collective C2 maturity approaches are more efficient.*

Efficiency was measured as a function of effectiveness in two dimensions: time and effort.

Time-efficiency results obtained were consistent with this hypothesis for all approaches except for EDGE, since its value was below COLLABORATIVE. Although EDGE reached a high time-efficiency in two runs, overall result was penalized due to a bad run (L5-01).

Effort-efficiency results obtained were consistent with this hypothesis for all approaches except for EDGE, since its value was below COLLABORATIVE and even COORDINATED. In fact, a surprising result was having a COORDINATED run (L3-04) obtaining highest effort-efficiency (despite the fact that all other runs obtained very low efficiency values as a result of their effectiveness). Moreover, effort was measured per approach and COORDINATED spent less than DECONFLICTED, COLLABORATIVE and EDGE. Hence, if effective, a COORDINATED approach may be very efficient regarding effort spent. On the other hand, EDGE always spent more effort than other approaches. Hence, a single low effective run degraded overall EDGE cost-efficiency results.

[3] *Higher collective C2 maturity approaches are more agile.*

Given its novelty, Agility concept, and its application in organizations, is currently under analysis by researchers and groups, such as CCRP FACT[18] group and NATO SAS-085[19]. Therefore, we deemed essential to consider outputs from these groups before attempting to capture and measure Agility in ELICIT.
This hypothesis therefore will be covered by future research work.

[7] *Organizations require a minimum level of maturity to be effective in ELICIT.*

Effectiveness of the several approaches in ELICIT varied across runs:

- Only COLLABORATIVE and EDGE reached an average value above 50% effectiveness. COLLABORATIVE presented the best results in a consistent way (80% effectiveness, ranging between 67% and 100%).
- A COORDINATED run reached a high mark of 92%, despite the fact that all other runs had a mediocre score and average score was 34%.
- Both CONFLICTED and DECONFLICTED reached low average scores.

This suggest that requisite maturity in ELICIT is COLLABORATIVE or COORDINATED whenever a fit subject is placed in CTC role.

[18] Information about FACT (Focus, Agility, and Convergence Team) is available at http://www.dodccrp.org/html4/events_fact.html
[19] NATO SAS-085 (C2 Agility and Requisite Maturity) official page: http://www.rta.nato.int/ACTIVITY_META.asp?ACT=SAS-085

[8] *Increasing the degree of difficulty in ELICIT require organizations to increase their level of maturity to maintain effectiveness in ELICIT.*

Evaluation of this hypothesis required running factoids set 2 (most difficult set) across all approaches and determine respective impact on effectiveness. This condition was not met and, therefore, this hypothesis cannot be evaluated.

Finally, an interesting fact to derive from Table 10 is that C2 approaches assessment scores are, in overall, consistent with N2C2M2 model, NCW tenets and NCW value chain: increasing the C2 approach maturity of an organization, increases the extent of shared information and critical information available, result in better interactions, broader extent of correct understanding, self-synchronization and increased organizational effectiveness and efficiency.

We consider that there are still aspects to further investigate and understand regarding validation of the N2C2M2, such as achieving a better understanding of the non-compliances between the N2C2M2 model and some experimentation results (especially regarding EDGE and COORDINATED approach).
Moreover, there is a clear need to increase the amount of experimental data (i.e., valid ELICIT runs) for analysis to ensure robustness of results and findings obtained so far. In this direction, the agent-based ELICIT (Ruddy 2009) presents a cost-effective way to replicate experiments described herein, but resorting to software-agents instead of humans, and exploit further manipulations in the context of the N2C2M2 and NCW. Software-agents are fully controllable and it is easier to collect 17 of them to run an experiment, although at the cost of losing the richness of the human complexity in the game. Hence, we intend to complement agent-based simulated runs with runs using real-persons in our ELICIT experiments.

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Content herein is deeply intertwined in the work of the SAS-065, a NATO RTO group, which worked from 2006 to 2009 to develop the NATO NEC C2 Maturity Model (N2C2M2), a new model scrutinized through several validation processes, including experimentation.
Therefore, this work is the result of a rich and insightful collaboration undertaken by international scientists, experts, enthusiasts and friends to whom we wish to express our deepest gratitude and acknowledgements:

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Annexes

OVERVIEW OF THE ELICIT PLATFORM

ELICIT is a research and experimentation programme developed for the CCRP to conduct research related with collaboration, information sharing and trust. The platform allows instantiating different C2 approaches and observation of behaviors and dynamics in the information, cognitive and social domains. ELICIT is presented in detailed in (Ruddy 2008).

Logic of Factoids Sets

A Factoid is a piece of information which may contain important information to determine the *Who*, *What*, *Where* and *When* of a future attack. Factoids are categorized as:

- Key (K): if they contain information which is essential for a specific problem space.
- Expertise (E): if they contain information which is essential for solving the problem and may be important for more than one specific problem space. Expertise factoids model the expertise that a team leader might have.
- Supportive (S): if they contain information which supports key and expertise facts.
- Noise (N): if the information they contain is irrelevant to determine the problem.

ELICIT has four baseline sets of factoids, each consisting on a different problem to solve. They should comply with the following generic rule: each factoid set has 68 factoids, whose category is distributed as follows: 17 are Key and Expertise, 17 are Supportive and 34 are Noise. Hence, ratio of relevant information and noise is 50%.
All factoids are distributed by server in three waves as follows:

- Wave 1 (t=0 min): 34 factoids are distributed by server (each subject receives 2 factoids), in which 9 are K/E, 9 are S and 16 are N. Special roles (e.g., team leaders and coordinator), if applicable, should receive an expertise factoid but an unintended deviation was produced due to new organization setup (see remark).
- Wave 2 (t=5 min): 17 factoids are distributed by server (each subject receives 1 factoid), in which 8 are K/E/S.
- Wave 3 (t=10 min): 17 factoids are distributed by server (each subject receives 1 factoid), in which 8 are K/E/S.

However, in the scope of this work, all factoids were analyzed and reclassified resulting in factoids sets displaying minor deviations from this generic rule. This is explained in detailed in following subsections.

Next chart illustrates factoids distribution across time for an Edge run:

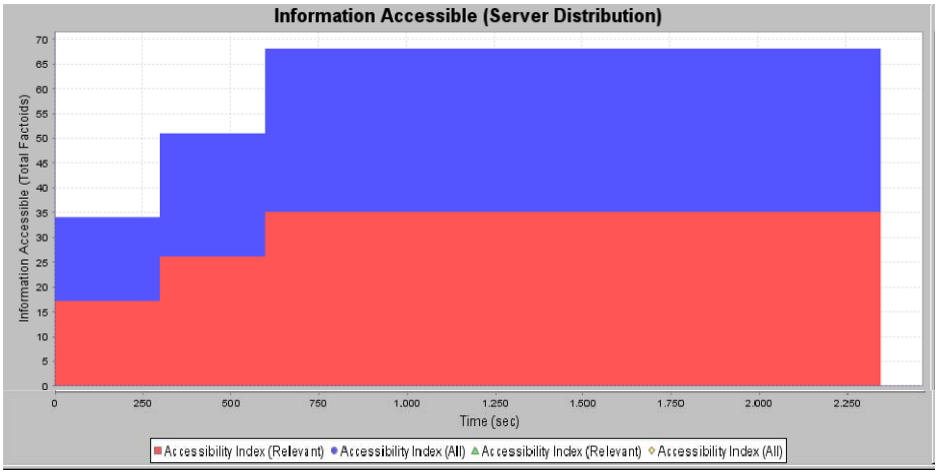


Figure 19 - Information Accessible Chart (server factoids distribution)

Likewise, the following table presents factoids distribution for an Edge run with added feature to discriminate which factoid is distributed to which subject.

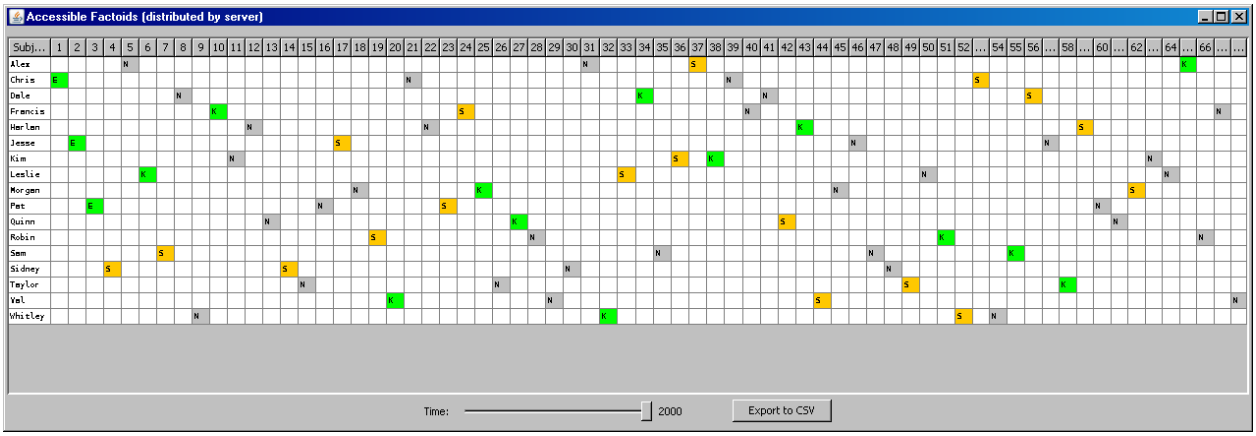


Figure 20 - Information Accessible Table (server factoids distribution)

Analyzing both figures it is possible to confirming that:

1. All information (i.e., 68 factoids) is accessible at 6000 sec (10 min)
2. Server only distributes unique factoids to subjects, that is, it doesn't disseminate the same factoid to more than one subject (in other words, shared information resulting from server factoids distribution is always zero between any set of subjects).
3. K/E, S and N factoids are evenly distributed to subjects (except cases noted in the beginning of this section)

Examples of factoids:

- Key factoid (who): *The Lion is known to work only with the Azure, Brown, or Violet groups*
- Expertise factoid (what): *There will be a suicide bomber attack at a school*
- Supportive factoid (when): *The Blue, Silver, Turquoise and Gray groups prefer to attack in daylight*

Solution Logic

All factoids sets have different factoids and solutions. The solution logic is similar for all sets and also follows a similar (but not equivalent) distribution in factoids' classification.

Factoid Set Nbr	Nbr Factoids	Nbr K/E	Nbr S	Nbr N	KE ratio	KES ratio	Noise ratio
1	68	16	18	34	0.24	0.50	0.50
2	68	17	18	33	0.25	0.51	0.49
3	68	15	20	33	0.22	0.51	0.49
4	68	15	20	33	0.22	0.51	0.49

Table 11 - Factoids classification distribution per set

The solution logic is explained in next subsections.

1.1.1 Factoid Set 1

Solution is:

- Who: Violet
- What: Financial Institution
- Where: Psiland
- When: April, 5, 11:00AM

The next table presents factoids that allow to unequivocally determining each part of the solution:

Factoid Domain / Solution Domain	Possible Solutions Set	Who	What	Where	When	OBS:
Who	Azur, Brown, Coral, Chartreuse, Gold, Purple, Violet	1,8,10,13,14				1,8: is A, B, V 10: not A 13,14: not B
What	Embassies (20x) Dignitaries Fin. Inst.		2, 22, 29	39, 41, 42, 47		42: is E, D, IF 29: not D 2, 22, 39, 41: all embassies out
Where	Tauland Epsilonland Chiland Psiland Omegaland	1		3, 22, 42, 47		42: provides who options (T,E,C,P,O) 22: not T, not E 47: not O 1,3: not C
When	Month: April, June, any Day: 5,10 T: 11:00AM	1, 8			53, 59, 62	1,8: Lion is involved and is a person 53: is 11:00AM 59: is April 1,8,62: is day 5 Modified factoid 53 specifies AM (day).

Table 12 - Factoids necessary to determine solution for Set 1

Remarks:

- 41 is 'N' but should be K'
- K/E factoids not necessary: 4 (E), 31 (K)

Factoids Reclassification

Original	Modification
4E	4S
31K	31S
41N	41K

1.1.2 Factoid Set 2

Solution is:

- Who: Aqua
- What: Deltaland Embassy
- Where: Alphaland
- When: May, 27, 3:00PM

The next table presents factoids that allow to unequivocally determining each part of the solution:

Factoid Domain / Solution Domain	Possible Solutions Set	Who	What	Where	When	OBS:
Who	Aqua, Orange, Indigo, Lime, Marron, Red, Tan	1, 12, 14, 17, 18				1, 12: is A, O, T 14: not T 17,18: not O
What	Embassies (20x) Dignitaries Fin. Inst.		2, 26, 33, 35	43, 46		35: provides what options (D, Embassies) 26: not A,B targets 33, 35: not Dignatary 43: not G-embassy, not B-embassy (can only be D-embassy)
Where	Tauland, Epsilonland, Chiland, Psiland ou Omegaland	1		3,46, 51		46: is A,B,G,D,E 1, 3: not G, not D, not E 51: not B
When	Month: May, June Day: 16, 27 T: 3:00PM, night, day	1, 12, 14			55, 57, 63, 66	1,12,14,55: needs who 57: is 3:00PM 63: is Maio 66: is day 27

Table 13 - Factoids necessary to determine solution for Set 2

Remarks:

- 55 is 'N' and should be 'K' (55 replaces 17K and 18K – actually, the fact that Orange recruits locals, doesn't mean they don't recruit non-locals also – as such, Lion could also work with Orange)
- K/E factoids not necessary: 4 (E)

Factoids Reclassification

Original	Modification
4E	4S
55N	55K

1.1.3 Factoid Set 3

Solution is:

- Who: Magenta
- What: Southern Oil Pipeline Terminal
- Where: Thetaland
- When: August, 15, 11:00PM

The next table presents factoids that allow to unequivocally determining each part of the solution:

Factoid Domain / Solution Domain	Possible Solutions Set	Who	What	Where	When	OBS:
Who	Beige, Cyan, Green, Fuchsia, Ivory, Magenta, Yellow	1	2,29		59	1,2,29: is M,C 59: not C
What	Oil Pipeline, Railway station, Power supply station	1	2, 21, 23, 30			23: is Oil,Train, Power. 1,2, 21: not Power 1,2,30: not Train (54 and 67 indicates a 'Southern pipeline' but it isn't conclusive)
Where	Zetaland, Thetaland, Iotaland, Kappaland, Lambaland		(needs what)	3, 40, 50		23: is Z,T,I,K,L 1,3: not Z 40 (with what): not I 50 (with what): not K,L
When	Month: June, August Day: 14, 15 T: 11.00PM, night, day				4, 54, 61, 67	4, 61: is 1:00PM 54,67: is 15, August

Table 14 - Factoids necessary to determine solution for Set 3

Remarks:

- 15 is 'N and should be 'S' (allows to eliminate directly an option – and discards 6K)
- 6 is 'K' and should be 'S' (see previous point)
- 59 is 'N' and should be 'S' (allows to eliminate directly an option).
- K/E factoids not necessary: 47 (K)
- Factoid 26N is never disseminated[20].

This factoid set doesn't provide a conclusive solution for What. Specifically, it is clear that target is an Oil Pipeline, but nowhere is explicated that it is the Southern pipeline (see factoids 54 and 67). We consider that solution may be obtained through logic but not resorting to provided factoids.
Hence, for analysis purposes, we consider 'Oil pipeline' as a correct answer.

Factoids Reclassification

Original	Modification
6K	6S
15N	15S
47K	47S
59N	59S

[20] factoidset3PT-17.txt file contains variation for metadata of factoid 26 which is different from others. Specifically:
Correct syntax: "44|N|3|16|2|5|Zetaland é um enclave"
Incorect syntax: "26|N|2|16|34|4|Todas as centrais eléctricas em Kappaland são propriedade do Estado"
The fifth element (34) in factoid 26 refers to non-existing dissemination wave (34).

1.1.4 Factoid Set 4

Solution is:

- Who: Magenta
- What: Secular School
- Where: Omicronland
- When: January, 1, 9:00AM

The next table presents factoids that allow to unequivocally determining each part of the solution:

Factoid Domain / Solution Domain	Possible Solutions Set	Who	What	Where	When	OBS:
Who	Blue, Gray, Silver, Teal, Turquoise	1, 6, 10, 19	2			1,2: not G, not Teal 2,6: not S, not R 2,10: not Turq 19 (OR 2,20): not B
What	Secular school, Religious school, Army base		2, 25, 27, 32,	43, 51		2,32: is RSchool, SSchool 51: not School in S 25,27,43: not RSchool (51 replaces 34)
Where	Muland, Xiland, Omicronland, Piland Sigmaland	(who)	2, 25, 27, 32	3, 38, 43, 51		32: provides what options 43: is M,X,O,P,S 2, 51: not S 2,25, 38: not M 2,27, 38: not X 3 (with who): not P
When	Month: January Day: 1 T: 9:00AM				55, 58, 65	55: is 1 58: is 9:00AM 65: is January

Table 15 - Factoids necessary to determine solution for Set 4

Remarks:

- 19 is 'S' but could be 'K' (allows to eliminate directly an option - although key factoid 20 allows same inference but is not straightforward).
- All K/E factoids are necessary (but 20K may be replaced by 19S)
- 63 is 'N' but could be 'S' (moreover, if 'needs time' is interpreted strictly, could eliminate an option - Cyan - becoming 'K')
- Factoid 65 is incorrectly numbered as 56.

Factoids Reclassification

Original	Modification
4E	4S
19S	19K
20K	20S
34K	34S
63N	63S
65S	56S

DATA COLLECTION AND ANALYSIS PROCESS

The process to collect and analyze experimental data in ELICIT underwent the following stages:

- Setup and Preparation
- Experiment Run
- Data Collection
- Data Fixes
- Data Analysis

The process is depicted in Figure 21.

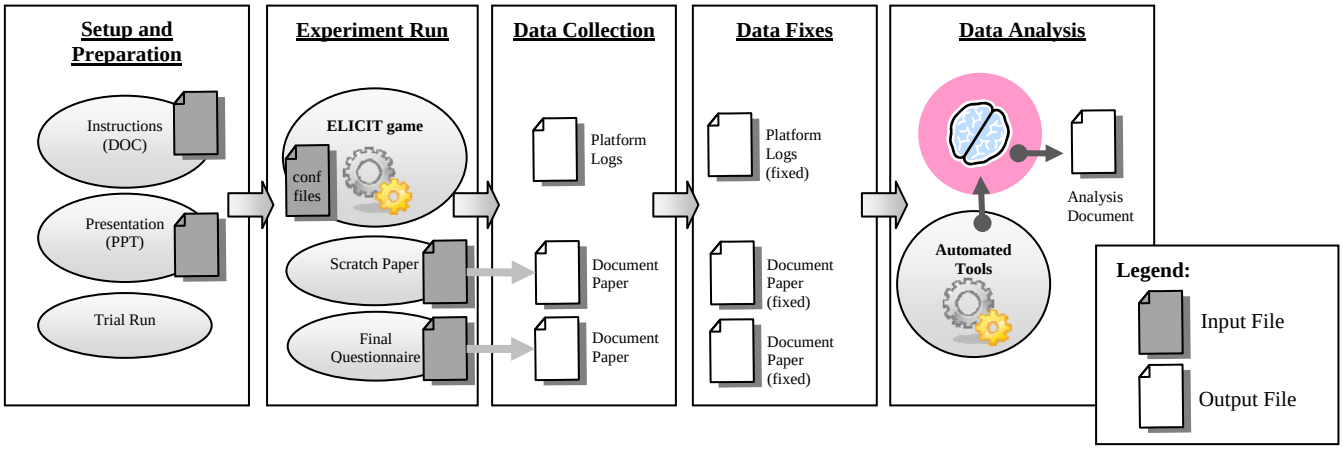


Figure 21 – Data Collection and Analysis Process

Setup and Preparation

This stage consists in the preparation of a ELICIT run, which include:

- Setting-up and configuring the platform (N2C2M2 Moderator Setup Instructions)
- Providing instructions to individuals
  - Instructions for players (per C2 Approach)
  - Presentation material (per C2 Approach)
- Conducting a trial run for training.

Experiment Run and Data Collection

This stage consists in the actual run of the experiment and collection of data:

- The ELICIT platform logs actions from individuals:
  - ELICIT log file (plain text file).
- Individuals may make notes in a Scratch paper, which is collected afterwards:
- Individuals fill a questionnaire at the end of the experiment:

Data fixes

This stage consists in fixing data collected in previous phase. For example, individuals identifies are entered as free text and may include syntax or semantic errors. Therefore, analysts are required to harmonize inserted text.

Data Analysis

This stage consists in the analysis of collected data. Automated tools will be use to generate quantitative data, to the extent as possible, although complementary qualitative analysis is also required.

DETAILED DESIGN OF EXPERIMENTS

Hereby is presented the ELICIT experimental design approach used in a set of ELICIT runs to observe the N2C2M2 Maturity Levels. It starts by describing what is common to all levels and then describes the differences associated with specific maturity levels.

Common Aspects

The following aspects are common to all levels:

a) **Entities:** There will be four team entities and a fifth single entity that takes on different roles in the runs representing Conflicted, De-conflicted, Coordinated and Collaborative approaches to collective C2. In the case of Edge C2, there will be seventeen entities with no *a priori* collective C2.
b) **Context:** The context is a complex endeavor --- "*one in which there are two or more force elements (entities) present and where one of more of the following conditions exists: the entities have overlapping intents; the entities are operating in the same area at the same time; and, the actions taken by an entity can come into conflict with those taken by another entities*." (Alberts and Hayes 2007).
c) **Scenario:** The scenario will be the existing ELICIT scenario of an imminent terrorist attack. Organic information will be provided to each of the seventeen individuals in three "waves". No individual or team will possess sufficient organic information to accomplish the task. Only by sharing information (factoids) can the task be accomplished. Factoid inter-dependence will be maintained, i.e., a factoid can be relevant to more than one aspect of the solution (e.g. "who" and "what").
d) **Task:** The task of the participants (individual, team and collective) are to identify the "who", "what", "where" and "when" of the attack within a specific timeframe.
e) **Information Sharing Capabilities:** Individuals can send factoids to other individuals (share action), post factoids to one or more websites (post action) and pull factoids from one or more websites (pull action). However, permissions will be manipulated per C2 Approach (see next section).
f) **Collaborative Capabilities:** For selected runs, individuals will have the ability to provide their "assessment" of importance (relevance) and/or trustworthiness of a factoid they share or post.
g) **Resource Contention:** The resources of interest in ELICIT are information and cognitive. Since information that is needed by one individual (team) can be in the possession of another one, a failure to share or provide access to this information can be considered as a conflict. Cognitive efforts (information processing and problem solving) are also required. There is a limited amount of this resource available and it must be allocated to the individual parts of the problem (e.g. who, what). Allocating less than sufficient cognitive resources to a part of the problem can also be considered a conflict.

Experimentation detailed design is presented next. Text in italic is quoted from (Alberts and Moffat 2007).

Model 1: Conflicted

COLLECTIVE OBJECTIVE: *None.*

COLLECTIVE C2: *None. The only C2 that exists is that exercised by the individual entities over their own forces or organisations.*

C2 IMPLICATIONS:

- *Each entity is pursuing its individual intent and taking independent action.*
- *Entities are operating in the area of operations without communicating with, sharing information with or engaging in any C2-related interaction. This means that there is no way to avoid some 'negative cross-impact' between or among force elements.*

ELICIT SETUP

Individuals and Teams are organized as follows:

- Four teams and one Coordinator (isolated).
- Each team has four members with one Team leader.

- No team external communications are allowed.
- Coordinator is isolated.

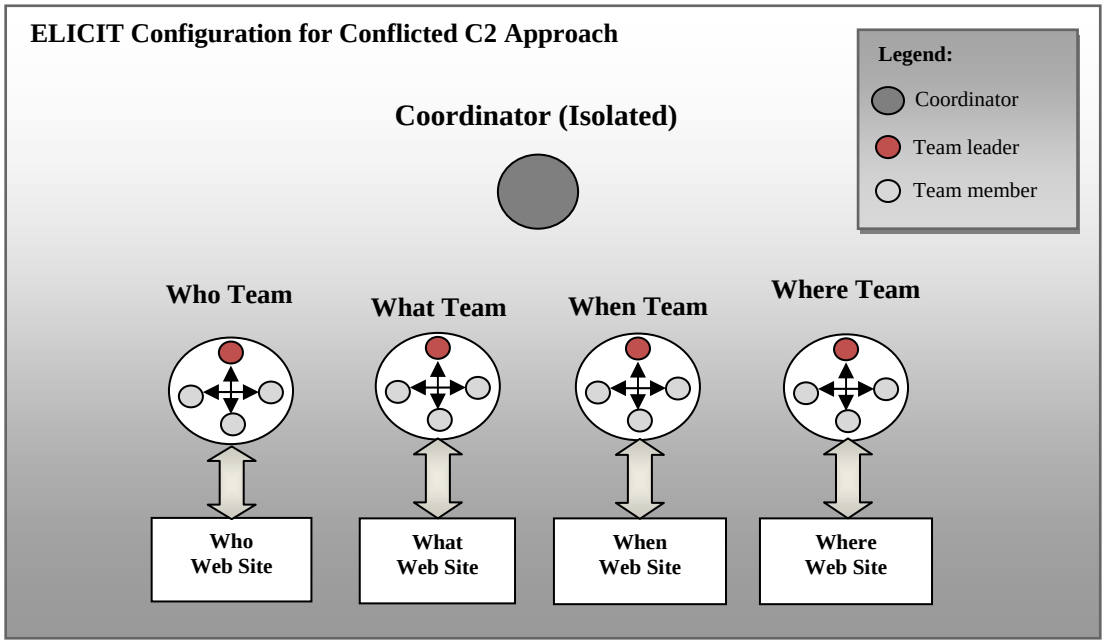


Figure 22 - ELICIT Configuration for Conflicted Collective C2 Approach

Each team operates independently its problem space dimension, namely:

- The *Who* team works in the *Who* problem space.
- The *What* team works in the *What* problem space.
- The *Where* team works in the *Where* problem space.
- The *When* team works in the *When* problem space.

Overall Coordinator (isolated) works in all problem space dimensions.

The following interactions are allowed:

- Members can *share Factoids* within their team.
- Members can *post* and *pull Factoids* from their team *website*.

The following interactions are not allowed:

- Members cannot *share Factoids* with members outside their team.
- Members cannot *post* and *pull Factoids* from others team's *websites*.
- (Isolated) Coordinator cannot *share Factoids* with teams and cannot *post* and *pull Factoids* from team's *websites*.

SUCESS CRITERION

Each Team pursues independent goals. Therefore, success occurs if each Team leader finds the correct solution to his problem space.
For analysis purposes (ONLY), overall organization success will be determined as all teams finding the correct solution.

EXPECTED RESULTS

The mission will never be accomplished due to insufficient levels of information quality and shared awareness among teams and individuals. Each team will form isolated clusters since there'll be no cross-team interactions.

Model 2: De-conflicted

COLLECTIVE OBJECTIVES: *The avoidance of adverse cross-impacts between and among the participants by partitioning the problem space.*

COLLECTIVE C2: *Limited to identifying potential conflicts and agreements to deconflict.*

C2 IMPLICATIONS:

- *Entities […] must be willing, at a minimum to accept a constraint on their plans or actions* (share information across teams). *In return they hope to avoid or remove any adverse cross-impacts.*
- *Limited peer to peer interaction in the Information domain must be sufficient to dynamically resolve potential cross-impacts.*
- *The main emphasis of C2 interactions and information flows is still on vertical interaction along 'stove-piped' chains of command within each entity.*

ELICIT SETUP

Individuals and Teams are organized as follows:

- Four teams and one Deconflictor.
- Each team has four Team members with one Team leader.
- Team leaders may distribute relevant information to Deconflictor.
- Deconflictor role is to distribute relevant information to Team leaders.

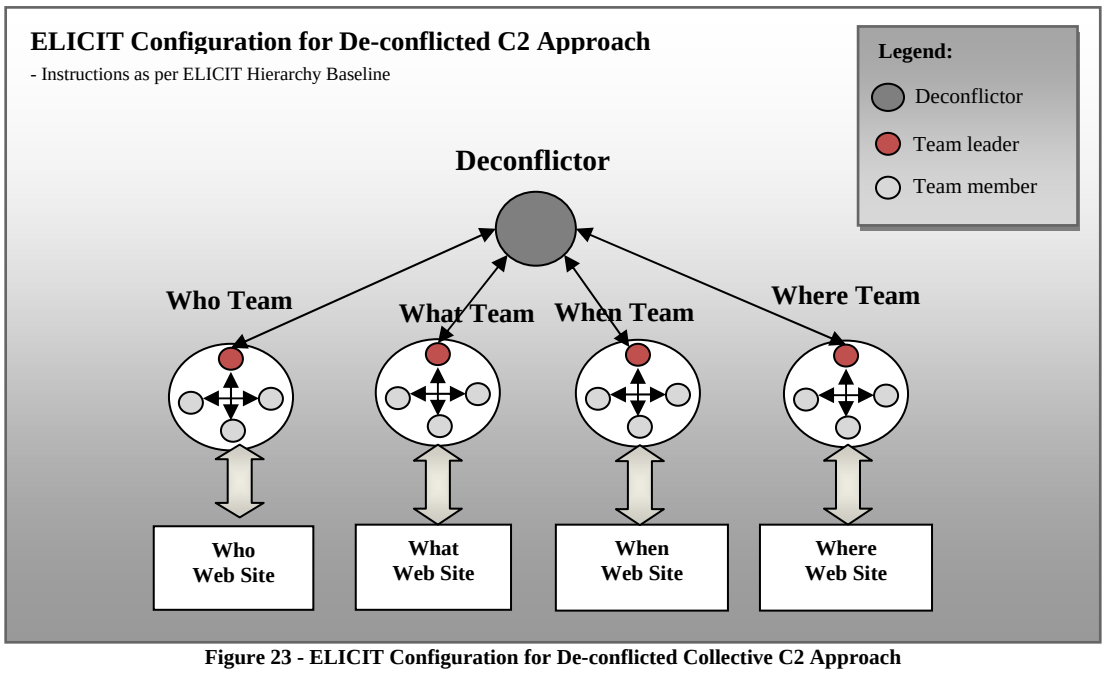


Figure 23 - ELICIT Configuration for De-conflicted Collective C2 Approach

Each team operates independently its problem space dimension, namely:

- The *Who* team works in the *Who* problem space.
- The *What* team works in the *What* problem space.
- The *Where* team works in the *Where* problem space.
- The *When* team works in the *When* problem space.

The Deconflictor role doesn't involve work in any of the problem space dimensions.

The following interactions are allowed:

- Deconflictor can *share Factoids* with Team leaders.
- Team leaders can *share Factoids* with Deconflictor.

- Team members can *share Factoids* within the team.
- Team members can *post* and *pull Factoids* from their team *website*.

The following interactions are not allowed:

- Deconflictor cannot *share Factoids* with Team members.
- Team members cannot *share Factoids* outside their team (incl. Deconflictor).
- Members cannot *post* and *pull Factoids* from others team's *websites*.
- Deconflictor cannot access (*post* and *pull Factoids*) to *websites*.

SUCESS CRITERION

Each Team pursues independent goals. Therefore, success occurs if each Team leader finds the correct solution to his problem space.
For analysis purposes (ONLY), overall organization success will be determined as all teams finding the correct solution.

EXPECTED RESULTS

There will be a limited amount of information sharing leading to a limited amount of shared awareness. Some individuals will solve their part of the problem, but few (if any) will solve the entire problem.
Strong formation of clusters within teams is expected. Active interactions are expected between DI and Team leaders (stove-pipes with centralized responsibility and decision making).

Model 3: Coordinated

COLLECTIVE OBJECTIVES: *To increase overall effectiveness by 1) seeking mutual support for intent, 2) developing relationships and links between and among entity plans and actions to reinforce or enhance effects 3) some initial pooling of non-organic resources, and 4) increased sharing in the information domain to increase the quality of information.*

COLLECTIVE C2: *Seeking opportunities to generate synergy by linking the plans and action(s) of one entity with those of another. Combine resources to achieve a necessary threshold for effective action or significant effects.*

C2 IMPLICATIONS: *This level of maturity begins to make it possible to form "task organised' forces with contributions from different entities to simplify interactions across the air, land and maritime domains, and other non-military actors.*

ELICIT SETUP

Individuals and Teams are organized as follows:

- Four teams and one Coordinator.
- Each team has four Team members with one Team leader.
- Coordinator interacts with Team leaders to provide necessary information and orientation to determine the correct solution.
- Team leaders assist Coordinator to determine the correct solution.

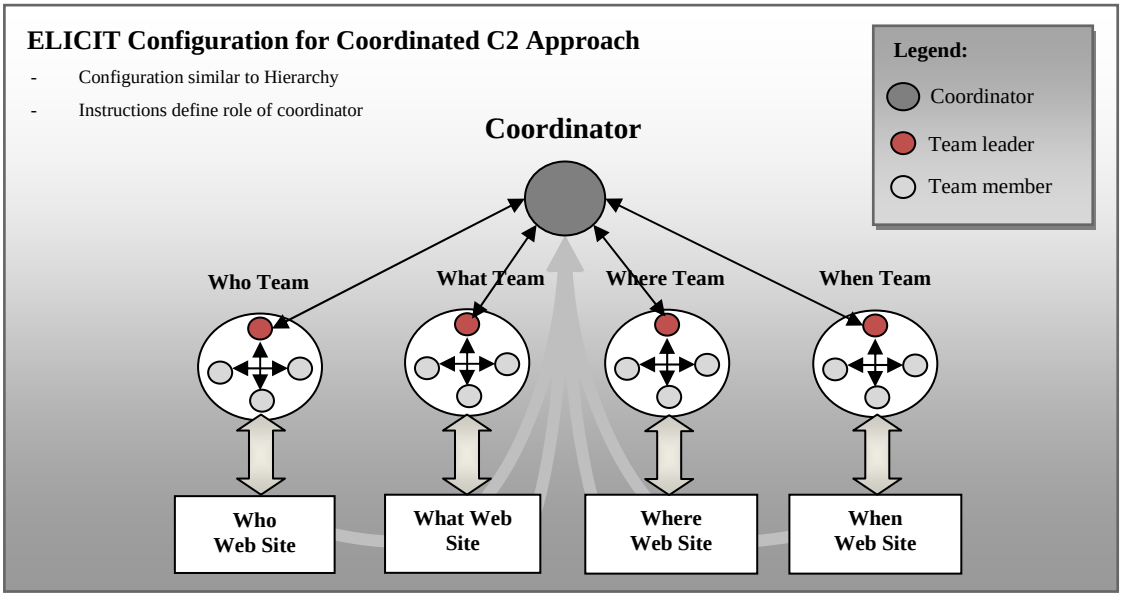


Figure 24 - ELICIT Configuration for Coordinated Collective C2 Approach

Each team operates independently its problem space dimension, namely:

- The *Who* team works in the *Who* problem space.
- The *What* team works in the *What* problem space.
- The *Where* team works in the *Where* problem space.
- The *When* team works in the *When* problem space.

The Coordinator works in all problem space dimensions.

The following interactions are allowed:

- Coordinator can *post* and *pull Factoids* to *websites*.
- Coordinator can *share Factoids* with Team leaders.
- Team leaders can *share Factoids* with Coordinator.
- Team members can *share Factoids* within the team.
- Team leaders and Team members can *post* and *pull Factoids* from their team *website*.

The following interactions are not allowed:

- Coordinator cannot *share Factoids* with Team members.
- Team members cannot *share Factoids* outside their team.
- Team leaders and members cannot *post* and *pull Factoids* from others team's *websites*.

SUCESS CRITERION

Organization success depends on the Coordinator finding the correct solution.

EXPECTED RESULTS

There will be increased information sharing leading to increased shared awareness. More individuals will solve their part of the problem and they will solve it sooner. More individuals will solve the entire problem and an overall solution will be available sooner.
However, clustering formation within teams is still expected, with frequent interactions between Coordinator and Team leaders (stove-pipes with centralized responsibility and decision making).

Model 4: Collaborative

COLLECTIVE OBJECTIVES: *To develop significant synergies by 1) negotiating and establishing shared intent and a shared plan, 2) establishing or reconfiguring roles, 3) coupling actions; 4) rich sharing of non-organic resources*[21]*, 5) some pooling of organic*[22] *resources; and 6) increasing interactions in the cognitive domain to increase shared awareness.*

COLLECTIVE C2: A collaborative mechanism at the collective level needs to be established to develop a single integrated plan.

C2 IMPLICATIONS:

- *Sharing of resources in addition to a requirement for more information sharing and interactions between and among the entities.*
- *Richer peer to peer interworking. To a far greater extent than is present in lower levels of C2 maturity, entities become interdependent. As a consequence, risk is pooled (like insurance).*
- *This C2 approach is appropriate for problems that are not fully decomposable in terms of objectives, space, time, and function and thus for which, a holistic approach is desirable.*

ELICIT SETUP

Individuals and Teams are organized as follows:

- Four teams and one Coordinator/Facilitator.
- Each team has four Team members with one Team leader.
- Coordinator/Facilitator collaborates with Team leaders and members to provide necessary information and knowledge to determine the correct solution.
- Team members may collaborate with members external to own-team (including Coordinator) to provide necessary information and knowledge to determine the correct solution.

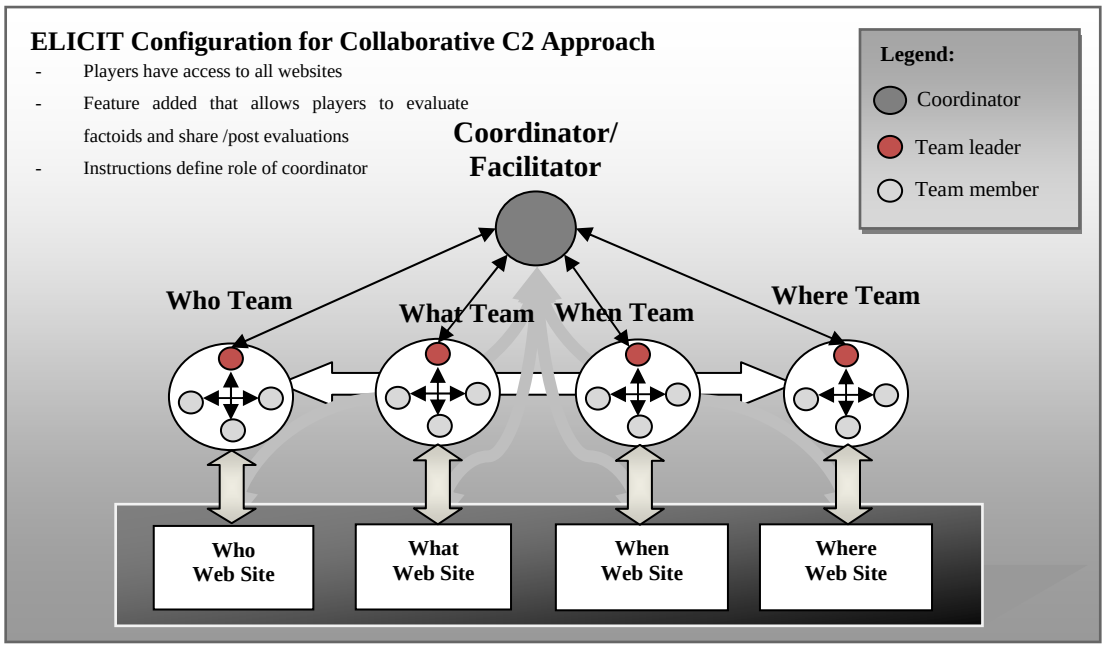


Figure 25 - ELICIT Configuration for Collaborative Collective C2 Approach

Each team operates independently its problem space dimension, namely:

- The *Who* team works in the *Who* problem space.
- The *What* team works in the *What* problem space.
- The *Where* team works in the *Where* problem space.

[21] Non-organic resources refers to resources not 'owned' by participants.
[22] Organic resources are those 'owned' by a participant.

- The *When* team works in the *When* problem space.

The Coordinator/Facilitator works in all problem spaces.

The following interactions are allowed:

- Coordinator can *post* and *pull Factoids* to *websites*.
- Coordinator can *share Factoids* with Team leaders and members, and vice-versa.
- Team members can *share Factoids* within members external to own-team.
- Team members can *post* and *pull Factoids* from *websites*.

The following interactions are not allowed:

- None.

Additionally, the following information can be attached to each Factoid share/post:

- Relevance;
- Trustworthiness.

SUCESS CRITERION

Organization success depends on the Coordinator finding the correct solution to all problem spaces AND Team leaders finding the correct solution to their problem space.

EXPECTED RESULTS

There will be significantly increased information sharing including significant amounts of reciprocity (sharing evaluations with those who share evaluated factoids) leading to significantly increased shared awareness. More (than at the coordinated C2 level) members will solve their part of the problem and they will solve it sooner. More members will solve the entire problem and an overall solution will be available sooner.
Less formation of team-based clusters with increased and *richer*[23] peer-to-peer interactions across members, leaders and coordinator. No stove-pipes, but some centralized responsibility and decision making (e.g., valid indentifies).

Model 5: Edge

COLLECTIVE OBJECTIVES: *To provide the enterprise with additional C2 approach options that involve entities working more closely together and with the ability to identify and implement the most appropriate approach to coalition C2 given the situation (e.g., mission, conditions, and set of coalition partners/contributing entities).*

COLLECTIVE C2: Emergent delegations of decision rights. These delegations are both dynamic and tailored as a function of the entities and the situation

C2 IMPLICATIONS:

- *Need for a high degree of shared understanding of a common (collective) intent.*
- *Need for rich and continuous set of interactions between / among participants, involving widespread information exchanges to allow the build up of shared understanding, and the ability (where appropriate) to self-synchronize*

ELICIT SETUP

Flat organization with 17 individuals (or entities). Individuals can collaborate and exchange information (e.g., Factoids with evaluation data) to provide necessary information and knowledge to determine the correct solution.

[23] Interactions are richer due to added feature that allows subjects to evaluate factoids in terms of relevance and trustworthiness in each share and post action.

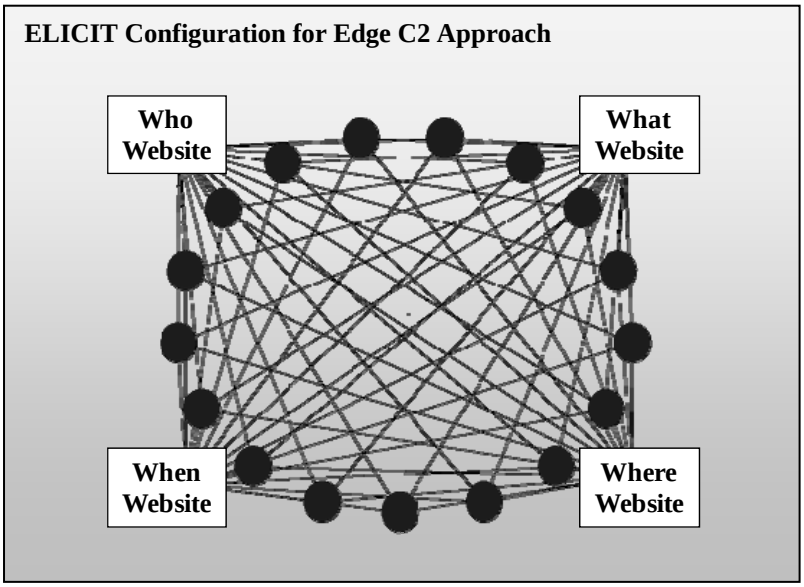


Figure 26 - ELICIT Configuration for Edge Collective C2 Approach

Individuals work in all problem space dimensions (i.e., *who*, *what*, *where* and *when*).

The following interactions are allowed:

- Individuals can *post* and *pull Factoids* to *websites*.
- Individuals can *share Factoids* with other individuals.

The following interactions are not allowed:

- None.

Additionally, the following information can be attached to each Factoid share/post:

- Relevance;
- Trustworthiness.

SUCESS CRITERION

Organization success depends on the majority of Individuals finding the correct solution to all problem spaces.

EXPECTED RESULTS

There will be dramatically increased information sharing (more than at the collaborative level) including significant amounts of reciprocity (posting evaluations on websites that have evaluations already posted and sharing evaluations with those from whom evaluated factoids were received) leading to dramatically increased shared awareness. More (than at the collaborative C2 approach) individuals will solve the complete problem and they will solve it sooner.
No clusters will be discernible (or will be ad-hoc, without prior engagement) with increased and richer (i.e., *Factoids* evaluation) peer-to-peer interactions across individuals. No stove-pipes, with decentralized responsibility and decision making.

MODEL INTERVENING VARIABLES

The experimentation model included relevant intervening variables, labeled as enablers/inhibitors. Their control or manipulation is out of the scope of this work (except for *Task Difficulty*). Nonetheless, they are described next, in Table 16, which may be used as reference for future related research.

Name	Description
Individual and Team Characteristics	These encompass the human complexity aspects which we cannot control (e.g., IQ, memory, language understanding, idiosyncrasies, (natural) propensity to share), although some we may influence. An example is sharing behavior and collaboration, which may be enabled (or inhibited) by setting collective (or isolated) goals. The following variables of interest will be monitored/observed: - Culture and Social[24]. - *Team Hardness* (SAS-050 2007): as a run progresses[25], new relations and links emerge. This is observable in ELICIT by, for example, the analysis of social ties (strong and weak) and, if applicable, the formation of clusters. - *Trust* (SAS-050 2007): the provided environment does not influence individuals' trust levels (e.g., use of anonymity, no wrong information, all necessary information available, no instructions to hoard and no antagonistic objectives)[26]. - *Training*: Training is provided to individuals by means of a trial run before conducting the exercise. The trial presents the same environment than the actual exercise, providing sufficient learning on how to interact with the platform. - *Experience*: We consider existing professional past experience will not play a major role in the ELICIT game[27]. - *Intelligence Quotient* (see *Individual Cognitive Abilities*, SAS-050): Students from the military academy (equivalent to university) will be used as subjects for the ELICIT experiments. Therefore, all individuals should have sufficient IQ levels to conduct the experiment (i.e., understand factoids semantically, discern those which are relevant and share/post appropriately). See also *Information Sharing and Collaboration.*
Task Difficulty	Currently, there are four ELICIT problems (i.e., four factoids sets): all have the same difficulty level except set 2 which is more difficult[28]. - Primary goal of the experiment is to observe that, for problems having the same difficulty level, more mature organizations outperform less mature ones (i.e., they are more effective and more efficient - better *Task Performance*). - Secondary goal of the experiment is to observe that, for increased problem difficulty, more mature organizations are more effective.
Quality of Information sources	Currently, factoids are not tagged or evaluated based on its source. This variable is currently fixed, although it may be manipulated for future experiments.
Quality of (Communications) Infrastructure	The communications infrastructure has sufficient capacity and performance to share and receive information (fixed value).
Platform	ELICIT software platform is also an important factor in the experiment: the way information is presented, the level interactions allowed between subjects (e.g., knowledge sharing) and functionalities (e.g., collaborative boards) are aspects which may be introduced or enhanced with influence on several network variables (e.g., information distribution, patterns of interactions, shared understanding).

Table 16 – Model intervening variables

[24] Recent research by nGenera (2009, Tapscott), based on more than 11 000 surveys, suggests that habits, skills and traits of NetGen, a generation born between 1977 and 1997, are significantly different than those generations before. Tapscott identified NetGet main differentiating characteristics, when compared with previous generations, as: need for freedom, need to customize and personalize, scrutinizers, integrity and open, wants entertainment and play, collaborative (social networks), want *speed*, and innovative. Inherent to this generation is a native understanding and operation of new technologies and internet 2.0. NetGen people are starting to enter the work force, including military, and their open, collaborative and social practices clash with industrial age practices.
[25] Variable time is implicit here.
[26] See (Powley and Nissen 2009) for related ELICIT experimentation on trust (and mistrust).
[27] Team hardness optional package will specifically address this issue.
[28] 'What' solution for factoid set 2 has an increased option space than all other sets. Specifically, while all other sets present over 4 possibilities, set 2 allows 8 possibilities (e.g., attack will be at embassy of a coalition countries, which comprises 5 countries).

DATA TABLES AND CHARTS

Information Domain Scores

	Shared Info. Accessible		RELEVANT Shared Info. Accessible		Shared Info. Reached		RELEVANT Shared Info. Reached	
Run ID	BEST %	BEST % at time (sec)	BEST %	BEST % at time (sec)	BEST %	BEST % at time (sec)	BEST %	BEST % at time (sec)
L1-01	0%	-	0%	-	0%	-	0%	-
L1-02	0%	-	0%	-	0%	-	0%	-
L1-03*	0%	-	0%	-	0%	-	0%	-
L2-01	0%	-	0%	-	0%	-	0%	-
L2-02	0%	-	0%	-	0%	-	0%	-
L2-03	0%	-	0%	-	0%	-	0%	-
L2-04	0%	-	0%	-	0%	-	0%	-
L3-01	0%	-	0%	-	0%	-	0%	-
L3-02	0%	-	0%	-	0%	-	0%	-
L3-03*	0%	-	0%	-	0%	-	0%	-
L3-04*	0%	-	0%	-	0%	-	0%	-
L4-01	65%	1 351	65%	722	65%	1 855	65%	1 687
L4-02	80%	702	80%	684	30%	947	50%	1 432
L4-03	50%	622	65%	2 303	30%	1 656	30%	1 656
L4-04*	65%	234	65%	218	20%	1 626	20%	1 626
L5-01	65%	2 219	65%	677	50%	979	65%	1 139
L5-02	80%	1 304	65%	664	65%	1 093	65%	999
L5-03	80%	1 172	80%	652	0%	0	0%	0

* Early delivery of factoids from server as illustrated in Figure 3

Table 17 – Information Domain Scores: Shared Information

	Information Reached										
	CTC		TL WHO		TL WHAT		TL WHERE		TL WHEN		AVG TLs
Run ID	Best %	BEST % at time (sec)	Best %	BEST % at time (sec)	Best %	BEST % at time (sec)	Best %	BEST % at time (sec)	Best %	BEST % at time (sec)	Best %
L1-01	0%		20%	581	20%	473	20%	1869	10%	600	18%
L1-02	0%	-	10%	378	20%	1049	10%	175	10%	430	13%
L1-03*	0%	-	20%	520	10%	288	10%	86	20%	601	15%
L2-01	30%	1222	30%	1749	20%	624	20%	626	20%	928	23%
L2-02	50%	1074	20%	1385	20%	311	20%	600	30%	1440	23%
L2-03	30%	1113	50%	1964	30%	600	30%	612	50%	1362	40%
L2-04	30%	1016	30%	1431	30%	809	30%	1620	30%	848	30%
L3-01	65%	1049	20%	412	20%	629	20%	751	20%	1857	20%
L3-02	80%	735	20%	758	30%	1737	20%	775	20%	553	23%
L3-03*	80%	1420	20%	466	20%	304	20%	303	10%	128	18%
L3-04*	80%	1476	20%	342	20%	337	20%	1448	20%	1385	20%
L4-01	65%	838	80%	1453	65%	987	65%	1045	65%	913	69%
L4-02	80%	844	80%	866	80%	868	100%	976	50%	709	78%
L4-03	65%	984	50%	1496	65%	860	65%	1653	65%	1068	61%
L4-04*	80%	1608	50%	1016	30%	907	80%	1651	65%	486	56%
L5-01	-	-	-	-	-	-	-	-	-	-	-
L5-02	-	-	-	-	-	-	-	-	-	-	-
L5-03	-	-	-	-	-	-	-	-	-	-	-

* Early delivery of factoids from server as illustrated in Figure 3

Table 18 – Information Domain Scores: Information Reached and Reach per role

Information Reach and Information Reached by Subjects

Examples of **Information Reach by Subjects** per approach is presented in next tables. Colors are used to facilitate awareness of factoids relevance: K/E, S and N are colored Green, Orange and Grey respectively; WHITE cells means no subject access to factoid.

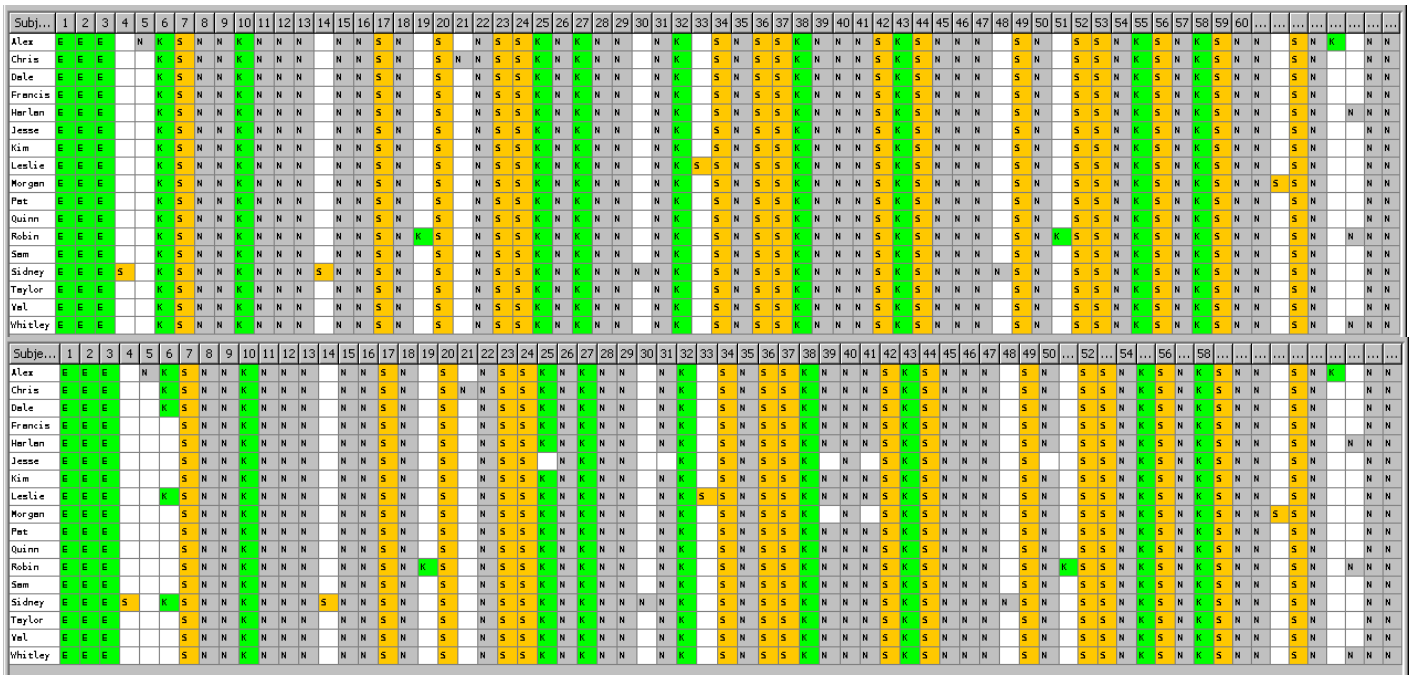


Table 19 – EDGE run L5-02: Information Reach (top) and Information Reached (bottom) by Subjects

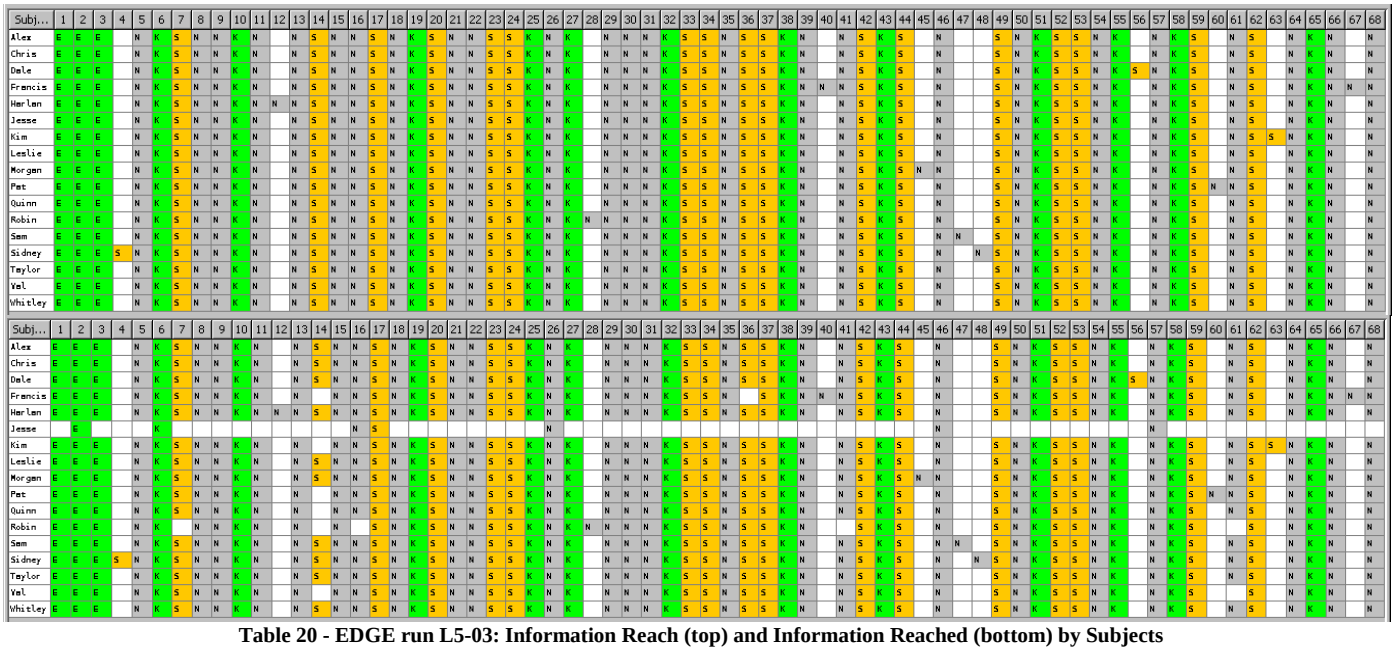


Table 20 - EDGE run L5-03: Information Reach (top) and Information Reached (bottom) by Subjects

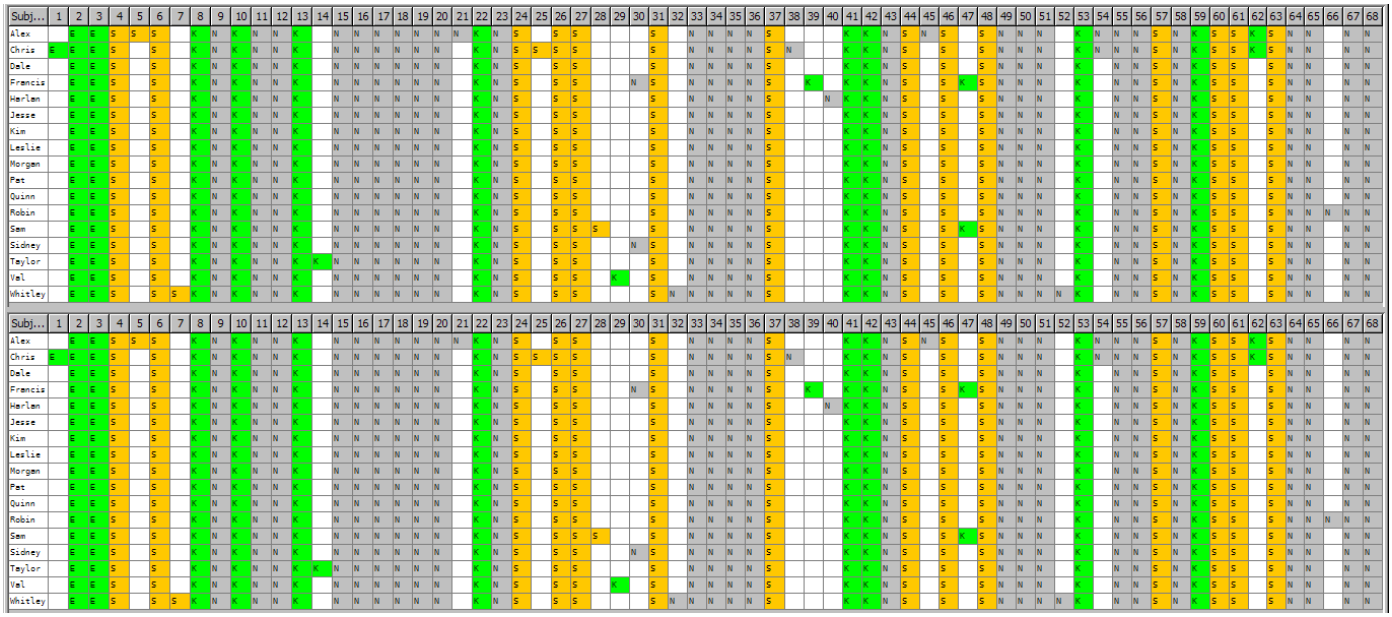


Table 21 – COLLABORATIVE run L4-01: Information Reach (top) and Information Reached (bottom) by Subjects

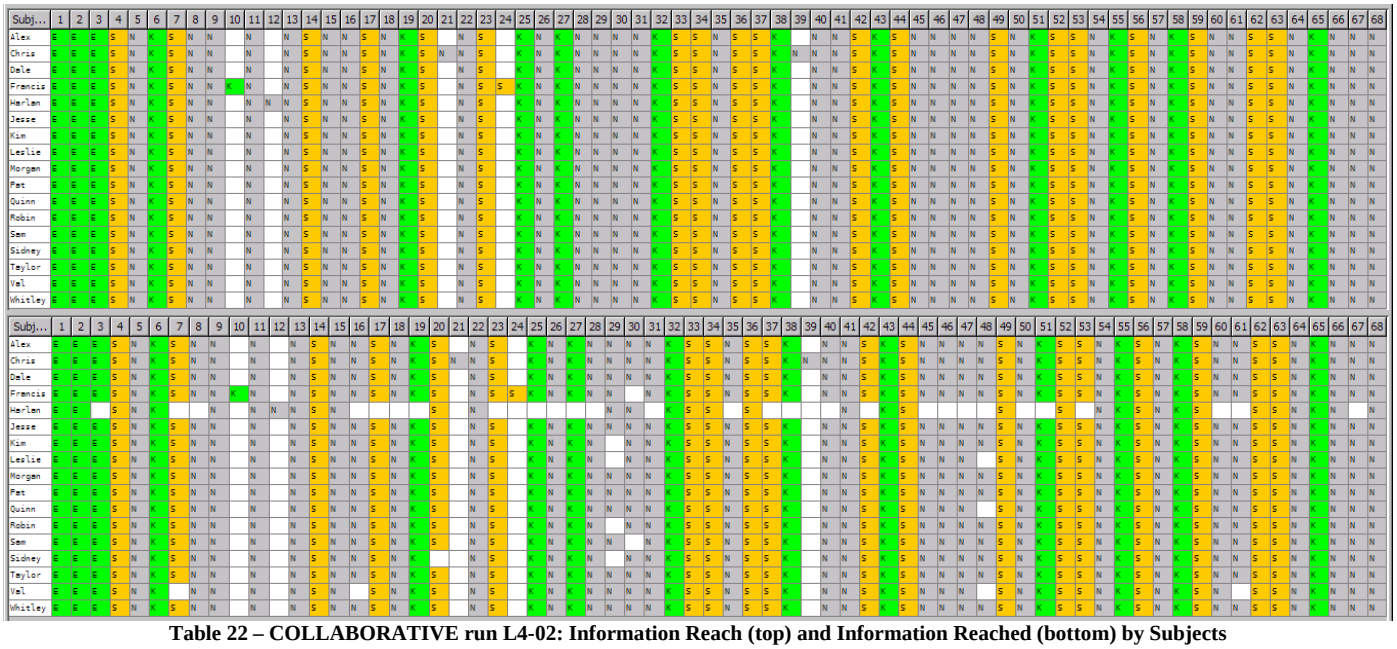


Table 22 – COLLABORATIVE run L4-02: Information Reach (top) and Information Reached (bottom) by Subjects

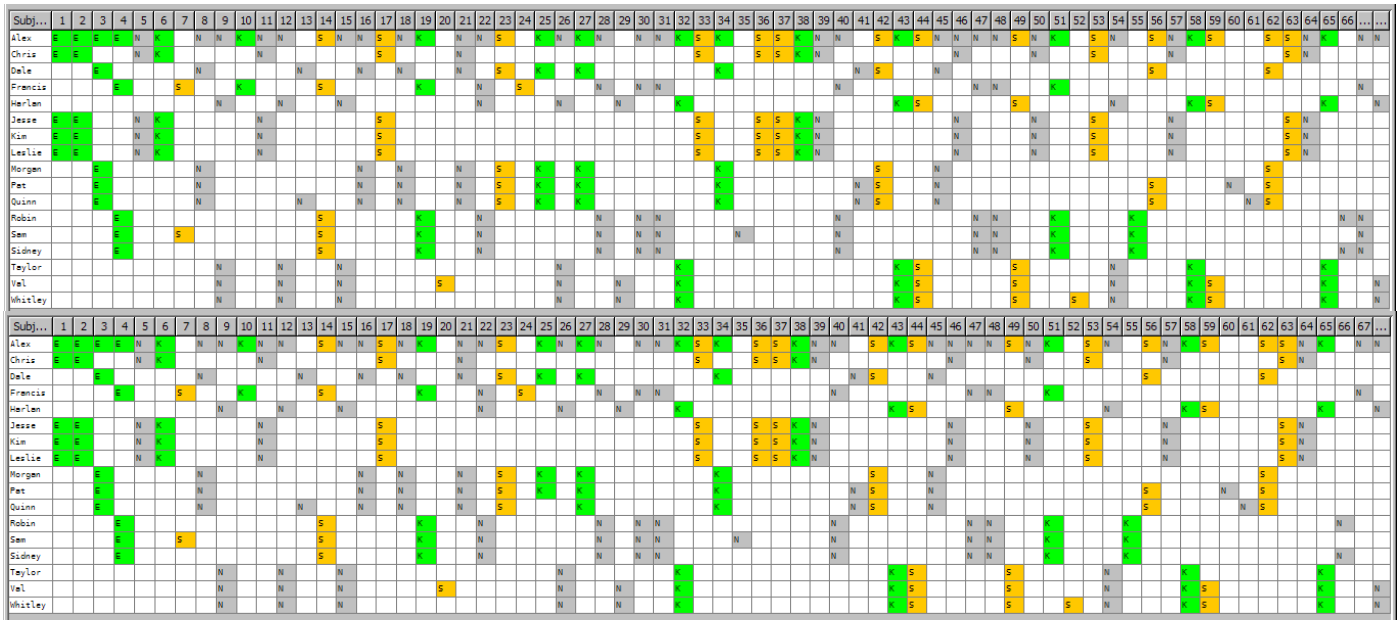


Table 23 – COORDINATED run L3-04: Information Reach (top) and Information Reached (bottom) by Subjects

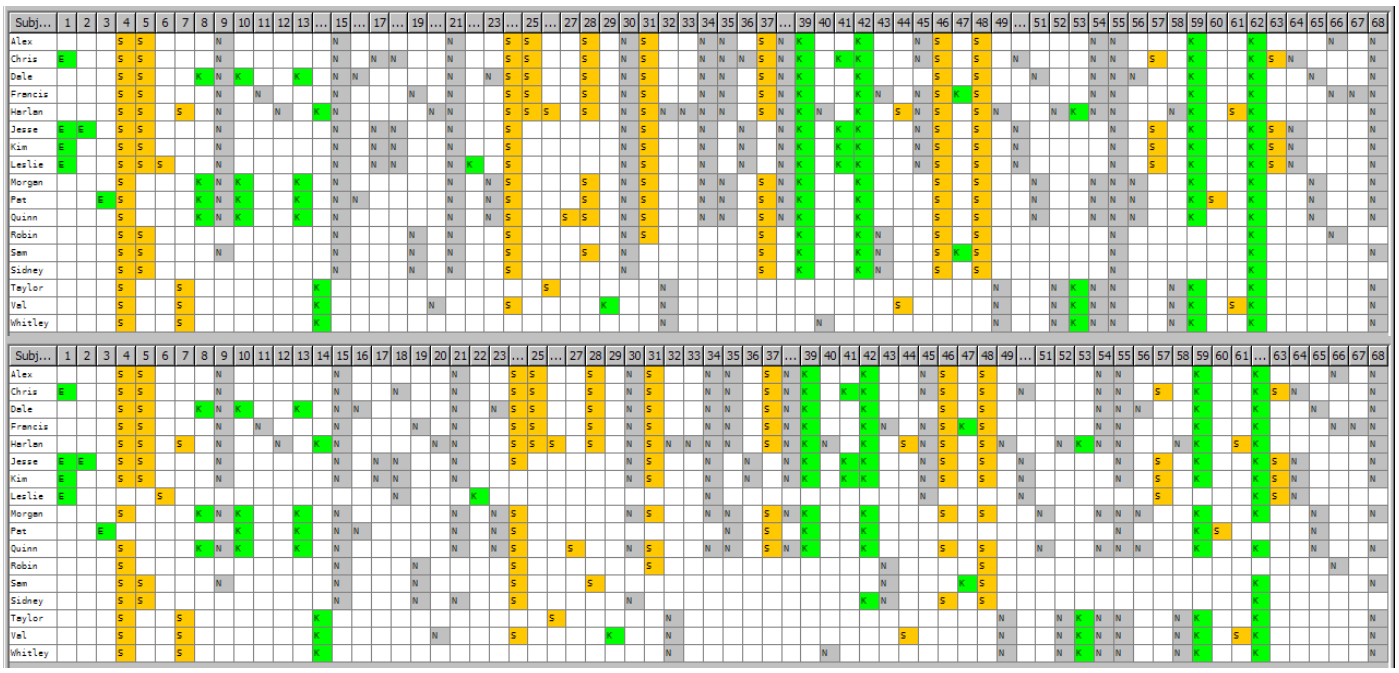


Table 24 – DECONFLICTED run L2-03: Information Reach (top) and Information Reached (bottom) by Subjects

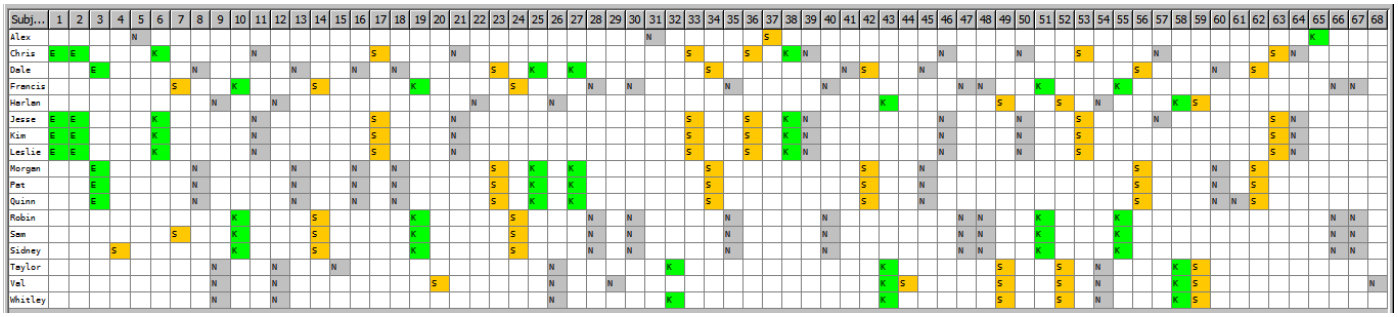


Table 25 – CONFLICTED run L1-01: Information Reach by Subjects

Nature of Interactions

Run ID	LEVEL	Shares per Hour	Posts per Hour	Pulls per Hour	Ids per Hour	OVERALL per Hour
L1-01	L1	264	133	164	65	625
L1-02	L1	129	88	143	47	407
L1-03	L1	118	188	203	45	553
L2-01	L2	309	135	242	63	749
L2-02	L2	264	190	156	65	675
L2-03	L2	363	174	109	49	695
L2-04	L2	455	217	145	42	858
L3-01	L3	285	91	235	40	651
L3-02	L3	321	211	161	70	763
L3-03	L3	141	121	140	49	451
L3-04	L3	237	128	208	73	645
L4-01	L4	102	161	729	71	1 062
L4-02	L4	150	272	655	101	1 177
L4-03	L4	95	137	654	66	951
L4-04	L4	168	372	667	51	1 258
L5-01	L5	137	140	1 443	91	1 811
L5-02	L5	102	187	1 055	105	1 449
L5-03	L5	69	180	1 082	60	1 391

Table 26 – Nature of Interactions: totals per hour

Value / APPROACH	Shares per Hour	Posts per Hour	Pulls per Hour	Ids per Hour	OVERALL per Hour
CONFLICTED	176	131	167	53	527
DECONFLICTED	**350**	178	164	54	746
COORDINATED	240	138	183	58	619
COLLABORATIVE	126	**228**	677	72	1 104
EDGE	105	167	**1 209**	**86**	1 567

Table 27 – Nature of Interactions: average of totals per hour per approach

In and Out Flows: Deviation from Average

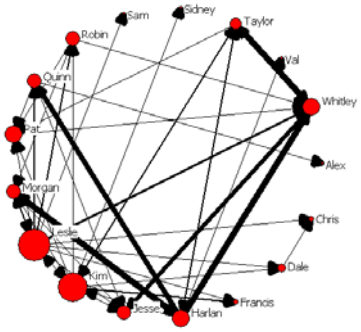
	CTC/TLs				TMs			
APPROACH	**IN**	**STD DEV**	**OUT**	**STD DEV**	**IN**	**STD DEV**	**OUT**	**STD DEV**
CONFLICTED	**4.1**	4.8	**-0.4**	3.0	**-0.5**	4.1	**0.9**	4.7
DECONFLICTED	**16.8**	12.0	**15.5**	23.3	**-7.0**	6.9	**-6.5**	10.7
COORDINATED	**12.4**	19.3	**3.0**	6.5	**-5.1**	5.4	**-1.2**	8.1
COLLABORATIVE	**3.0**	12.1	**-4.2**	5.3	**-1.2**	11.3	**1.7**	11.0
EDGE	-	-	-	-	**0.0**	19.1	**0.0**	9.0

Table 28 – Node Balance per Role

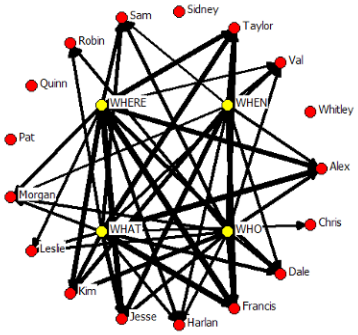
	Node Balance (IN)		Node Balance (OUT)	
RUN ID	**IN AVG Coord and TLs**	**IN AVG TMs**	**OUT AVG Coord and TLs**	**OUT AVG TMs**
L1-01	5.2	-0.6	-0.3	1.2
L1-02	2.0	0.1	-0.3	0.7
L1-03	5.0	-1.0	-0.5	0.7
L2-01	10.6	-4.4	5.6	-2.3
L2-02	10.8	-4.5	6.2	-2.6
L2-03	27.0	-11.3	26.6	-11.1
L2-04	18.7	-7.7	23.7	-9.9
L3-01	13.4	-5.6	6.2	-2.6
L3-02	13.7	-5.7	-0.6	0.3
L3-03	14.8	-6.2	5.6	-2.3
L3-04	7.7	-3.2	0.6	-0.2
L4-01	9.8	-4.1	-1.7	0.7
L4-02	1.8	-0.7	-7.1	2.9
L4-03	0.2	-0.1	-0.9	0.3
L4-04	0.0	0.0	-7.0	2.9
L5-01	-	-	-	-
L5-02	-	-	-	-
L5-03	-	-	-	-

Table 29 – Node Balance per Role

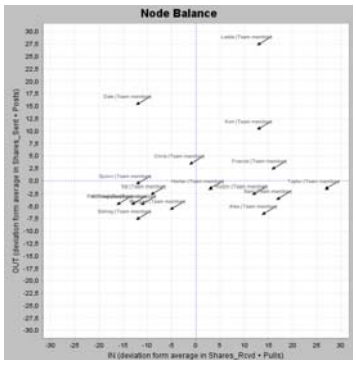
Sociograms

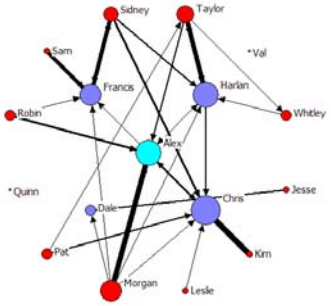


L5-02 Sociogram (no websites)

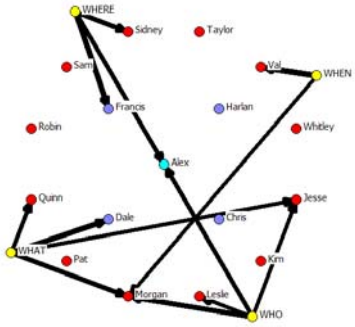


(10 or more interactions, incl websites)

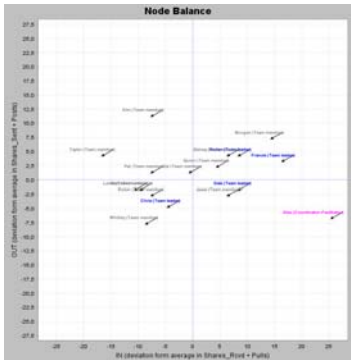


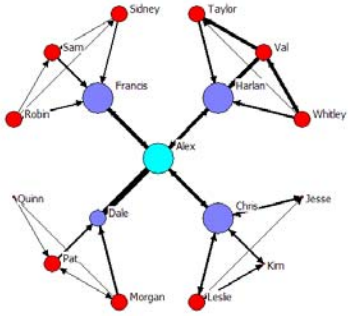


L4-01 Sociogram (no websites)

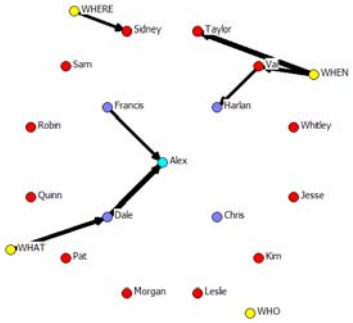


(10 or more interactions, incl websites)

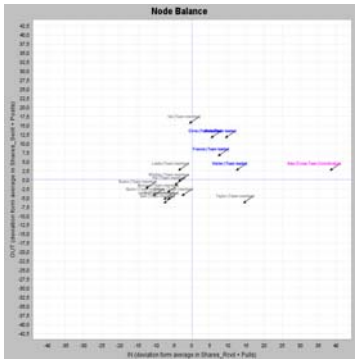


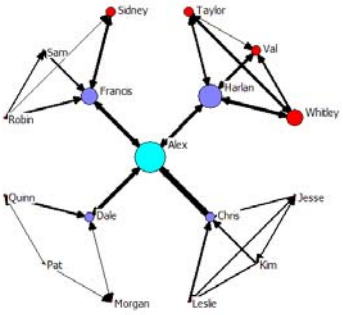


L3-01 Sociogram (no websites)

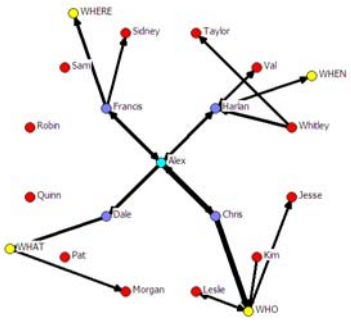


(10 or more interactions, incl websites)

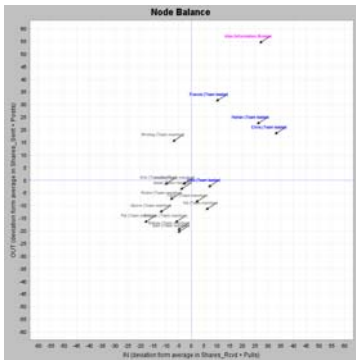


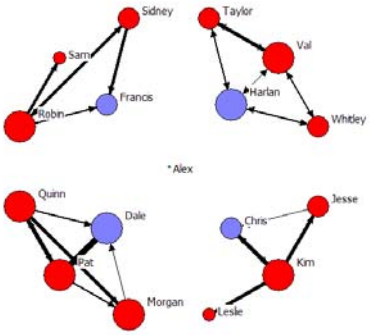


L2-04 Sociogram (no websites)

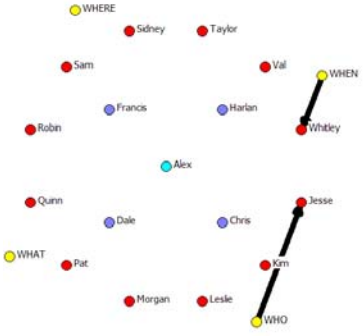


(10 or more interactions, incl websites)





L1-02 Sociogram (no websites)



(10 or more interactions, incl websites)

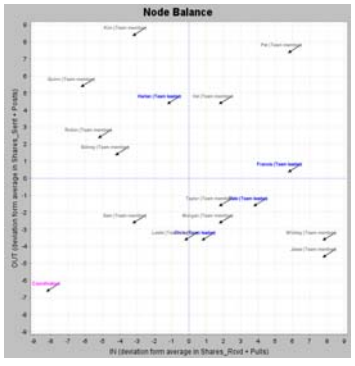


Figure 27 – Sociograms (first 2 columns) and IN-OUT Deviation per role (last column)

Quality of Interactions

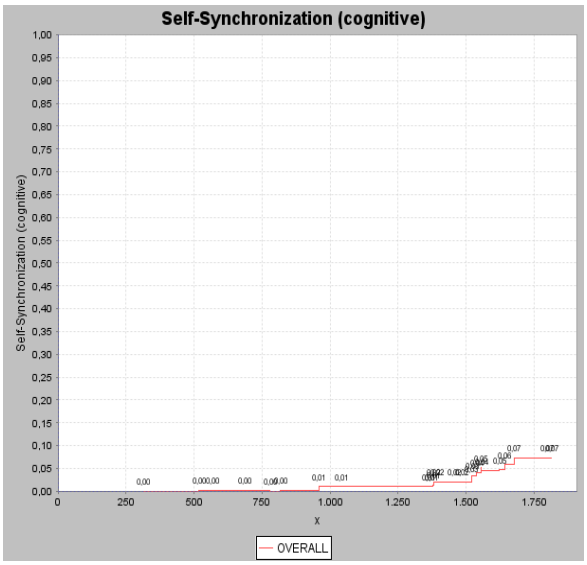
				Quality of Interactions (Shares and Posts)			Quality of Interactions (Shares and Posts)						
Log File	LEVEL	Factoid Set	Trial	TOTAL Value	TOTAL Value / Subject	Tendency	CTC	TLs (avg)	WHO TL	WHAT TL	WHERE TL	WHEN TL	Avg TMs
L1-01	L1	4	N	2.00	0.12	-	0.00	1.50	2.00	1.00	5.00	-2.00	
L1-02	L1	1	N	10.00	0.59	+	0.00	2.50	1.00	3.00	1.00	5.00	
L1-03	L1	3	N	8.00	0.47	+	0.00	1.25	2.00	1.00	-2.00	4.00	
L2-01	L2	1	N	-8.00	-0.47	-	-9.00	-3.00	-2.00	-10.00	2.00	-2.00	
L2-02	L2	4	N	-1.00	-0.06	=	5.00	0.50	-1.00	-5.00	0.00	8.00	
L2-03	L2	1	N	52.00	3.06	+	21.00	6.00	-1.00	8.00	14.00	3.00	
L2-04	L2	3	N	-15.00	-0.88	-	-13.00	-3.50	-15.00	0.00	-20.00	21.00	
L3-01	L3	1	N	11.00	0.65	+	-4.00	0.00	7.00	-7.00	2.00	-2.00	
L3-02	L3	3	N	18.00	1.06	+	11.00	1.75	3.00	2.00	-2.00	4.00	
L3-03	L3	2	N	26.00	1.53	+	6.00	1.50	2.00	4.00	-3.00	3.00	
L3-04	L3	4	N	3.00	0.18	-	-2.00	-0.25	2.00	4.00	-7.00	0.00	
L4-01	L4	1	N	15.00	0.88	+	1.00	-0.50	-3.00	2.00	1.00	-2.00	
L4-02	L4	4	N	63.00	3.71	+	1.00	1.50	3.00	0.00	2.00	1.00	
L4-03	L4	3	N	72.00	4.24	+	3.00	3.00	0.00	3.00	-1.00	10.00	
L4-04	L4	2	N	30.00	1.76	+	-2.00	3.75	7.00	3.00	0.00	5.00	
L5-01	L5	1	N	10.00	0.59	=							0.59
L5-02	L5	4	N	51.00	3.00	+							3.00
L5-03	L5	4	N	19.00	1.12	+							1.12

Table 30 - Quality of Interactions per run per role

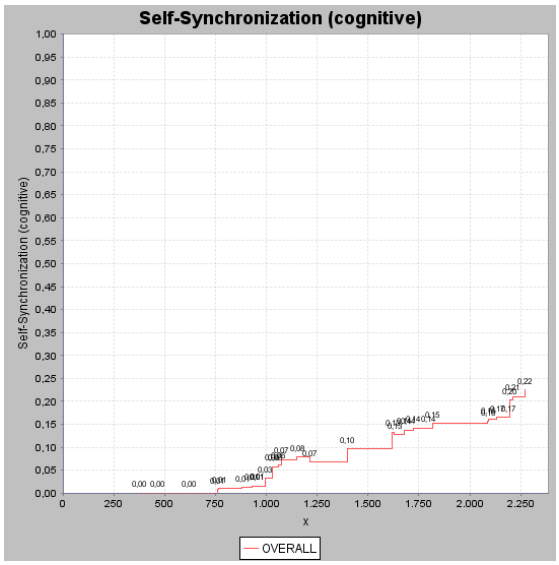
APPROACH	AVG	MIN	MAX
CONFLICTED	6.67	2.00	10.00
DECONFLICTED	7.00	-15.00	52.00
COORDINATED	11.63	0.17	26.00
COLLABORATIVE	45.00	15.00	72.00
EDGE	26.67	10.00	51.00

Table 31 - Quality of Interactions: mean value per approach

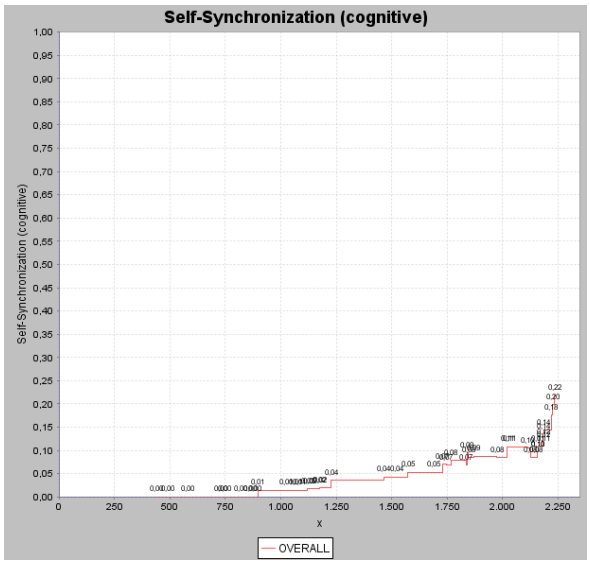
Cognitive Self-Synchronization



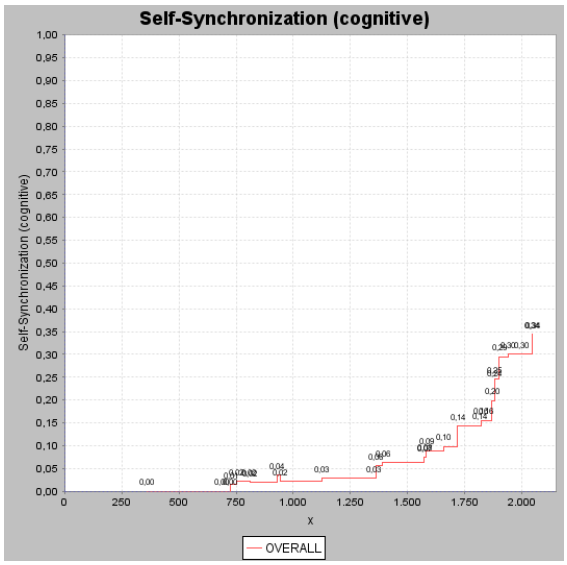
L1-02 Run



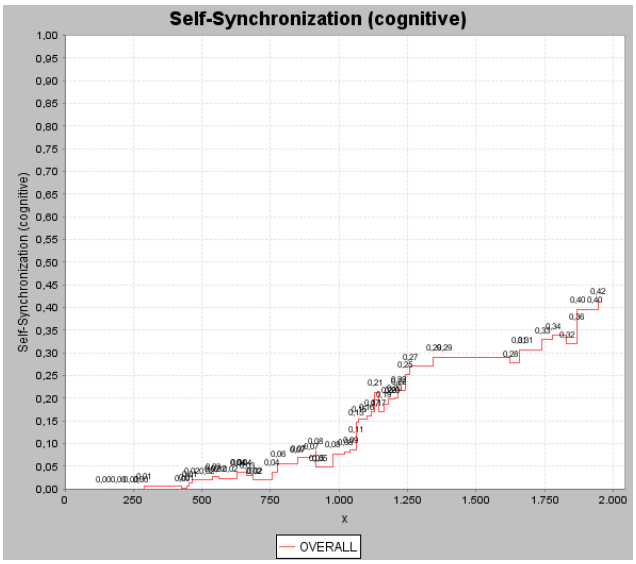
L2-03 Run



L3-04 Run



L4-04 Run



L5-02 Run

Figure 28 – Example Charts of time evolution of Disorder of Cognitive Self-Synchronization per approach

Cognitive Self-Synchronization							
ID	**WHO**	**WHAT**	**WHERE**	**WHEN (t)**	**WHEN (d)**	**WHEN (m)**	**OVERALL**
L1-01	0.10	0.09	0.14	0.10	0.00	0.00	0.088
L1-02	0.10	0.07	0.06	0.17	0.00	0.03	0.071
L1-03	0.00	0.00	0.00	0.00	0.03	0.03	0.004
L2-01	0.07	0.03	0.03	0.07	0.00	0.03	0.039
L2-02	0.00	0.00	0.13	0.17	0.07	0.03	0.052
L2-03	0.31	0.12	0.28	0.03	0.35	0.22	0.219
L2-04	0.23	0.17	0.21	0.20	0.07	0.12	0.179
L3-01	0.06	0.14	0.14	0.07	0.00	0.10	0.097
L3-02	0.17	0.14	0.23	0.00	0.07	0.07	0.145
L3-03	0.06	0.10	0.23	0.22	0.12	0.07	0.127
L3-04	0.25	0.17	0.34	0.20	0.00	0.12	0.215
L4-01	0.33	0.38	0.42	0.77	0.48	0.55	0.416
L4-02	0.53	0.38	0.25	0.62	0.20	0.48	0.386
L4-03	0.18	0.14	0.48	0.12	0.06	0.03	0.217
L4-04	0.28	0.29	0.39	0.48	0.34	0.41	0.331
L5-01	0.41	0.33	0.58	0.69	0.55	0.00	0.424
L5-02	0.35	0.43	0.40	0.84	0.55	0.03	0.401
L5-03	0.40	0.41	0.32	0.77	0.22	0.55	0.398

Table 32 - Cognitive Self-Synchronization per run

APPROACH	Mean	MIN	MAX
CONFLICTED	0.05	0.00	0.09
DECONFLICTED	0.12	0.04	0.22
COORDINATED	0.15	0.10	0.22
COLLABORATIVE	0.34	0.22	0.42
EDGE	0.41	0.40	0.42

Table 33 – Average value of Cognitive Self-Synchronization per approach

Cognitive Domain

Run ID	WHO	WHAT	WHERE	WHEN	TOTAL
L1-01	2(17)	0(17)	1(17)	1(17)	4 (64)
L1-02	2(17)	0(17)	2(17)	3(17)	7 (64)
L1-03	1(17)	0(17)	0(17)	2(17)	3 (64)
L2-01	1(17)	0(17)	1(17)	2(17)	4 (64)
L2-02	1(17)	0(17)	1(17)	3(17)	5 (64)
L2-03	7(17)	1(17)	6(17)	5(17)	19 (64)
L2-04	4(17)	5(17)	3(17)	4(17)	16 (64)
L3-01	0(17)	0(17)	1(17)	2(17)	3 (64)
L3-02	5(17)	1(17)	0(17)	2(17)	8 (64)
L3-03	1(17)	0(17)	4(17)	3(17)	8 (64)
L3-04	5(17)	1(17)	2(17)	3(17)	11 (64)
L4-01	5(17)	2(17)	2(17)	9(17)	18 (64)
L4-02	9(17)	3(17)	6(17)	9(17)	27 (64)
L4-03	4(17)	4(17)	9(17)	3(17)	20 (64)
L4-04	6(17)	0(17)	5(17)	8(17)	19 (64)
L5-01	8(17)	1(17)	3(17)	5(17)	17 (64)
L5-02	4(17)	4(17)	7(17)	9(17)	24 (64)
L5-03	7(17)	3(17)	6(17)	10 (17)	26 (64)

Table 34 – Extent of Correct Understanding

Overall Scores Table

							MoM - Effectiveness (by sol space)					Time Effectiveness (sec)
Run ID	WHO	WHAT	WHERE	WHEN (time)	WHEN (day)	WHEN (month)	WHO	WHAT	WHERE	WHEN	OVERALL	
L1-01	SILVER		SIGMALAND	9:00AM	14	MAIO	0.25	0.00	0.00	0.09	0.34	1 987
L1-02	AZUR	PSILAND	PSILAND	11:00AM	5	ABRIL	0.00	0.00	0.25	0.17	0.42	1 519
L1-03	IVORY	TERMINAIS DE GASODUTOS			15	AGOSTO	0.00	0.00	0.00	0.16	0.16	259
L2-01	VIOLETA	EMBAIXADA	TAULAND	11:00AM	-	ABRIL	0.25	0.00	0.00	0.17	0.42	2 376
L2-02		BANCO	PILAND	9:00AM	-	JANEIRO	0.00	0.00	0.00	0.17	0.17	1 698
L2-03	VIOLETA	DIGNATARIOS	PSILAND				0.25	0.00	0.25	0.00	0.50	2 270
L2-04	BEIGE	TERMINAL DE OLEODUTO	THETALAND	11:00PM	14	AGOSTO	0.00	0.25	0.25	0.17	0.67	2 174
L3-01							0.00	0.00	0.00	0.00	0.00	-
L3-02	MAGENTA	ESTACAO DE COMBOIOS	LAMBDALAND	-	DIA_SANTO	-	0.25	0.00	0.00	0.00	0.25	1 509
L3-03	JUPITER	EMBAIXADA	BETALAND	3:00PM	16	MAIO	0.00	0.00	0.00	0.17	0.17	1 283
L3-04	SILVER	ESCOLA SECULAR	OMICRONLAND	9:00AM	-	JANEIRO	0.25	0.25	0.25	0.17	0.92	1 840
L4-01	VIOLETA	INSTITUICAO FINANCEIRA	PSILAND	11:00AM	5	ABRIL	0.25	0.25	0.25	0.25	1.00	2 028
L4-02	SILVER	ESCOLA	OMICRONLAND	9:00AM	Terça-Feira	JANEIRO	0.25	0.00	0.25	0.17	0.67	1 698
L4-03	MAGENTA	TERMINAL DE OLEODUTO	THETALAND	11:00PM	-	-	0.25	0.25	0.25	0.09	0.84	2 355
L4-04	AQUA	EMBAIXADA	ALPHALAND	3:00PM	16	MAIO	0.25	0.00	0.25	0.17	0.67	1 899
L5-01	VIOLETA	EMBAIXADA DE TAULAND	EPSILONLAND	11:00AM	10	JAN, JUN	0.25	0.00	0.00	0.09	0.34	1 432
L5-02	SILVER	ESCOLA	OMICRONLAND	9:00AM	1	JANEIRO	0.25	0.00	0.25	0.25	0.75	1 241
L5-03	SILVER	ESCOLA	OMICRONLAND	9:00AM	1	JANEIRO	0.25	0.00	0.25	0.25	0.75	1 658

Table 35 – Identifications and Scores per run

APPROACH	WHO	WHAT	WHERE	WHEN	OVERALL	MIN	MAX
CONFLICTED	0.08	0.00	0.08	0.14	0.31	0.16	0.42
DECONFLICTED	0.13	0.06	0.13	0.13	0.44	0.17	0.67
COORDINATED	0.13	0.06	0.06	0.09	0.34	0.00	0.92
COLLABORATIVE	0.25	0.13	0.25	0.17	0.80	0.67	1.00
EDGE	0.25	0.00	0.17	0.20	0.61	0.34	0.75

Table 36 –Identifications Scores Average per approach

Effort Spent

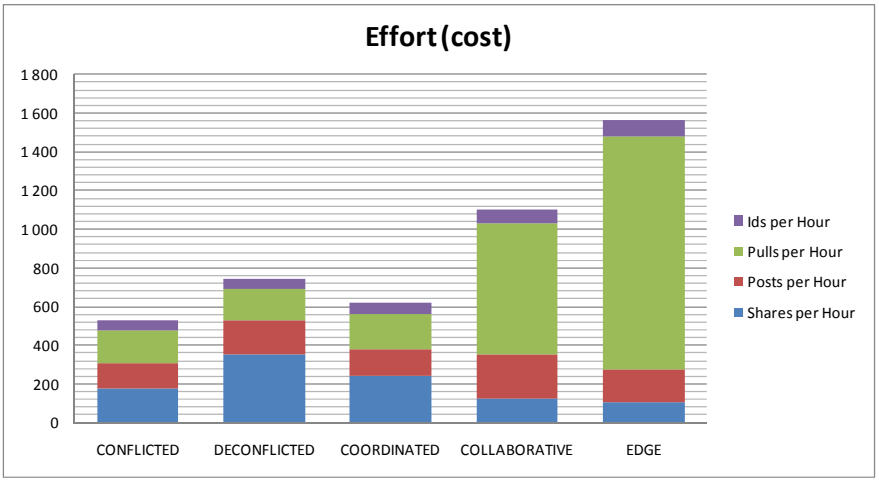
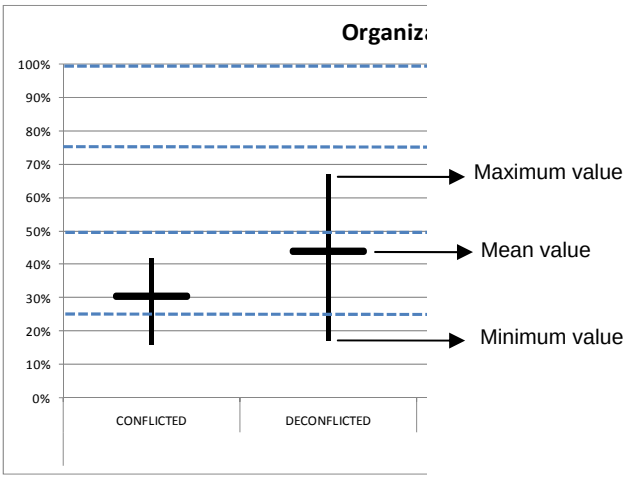


Figure 29 – Effort spent per approach

EXPLANATION OF STATISTICAL CHARTS



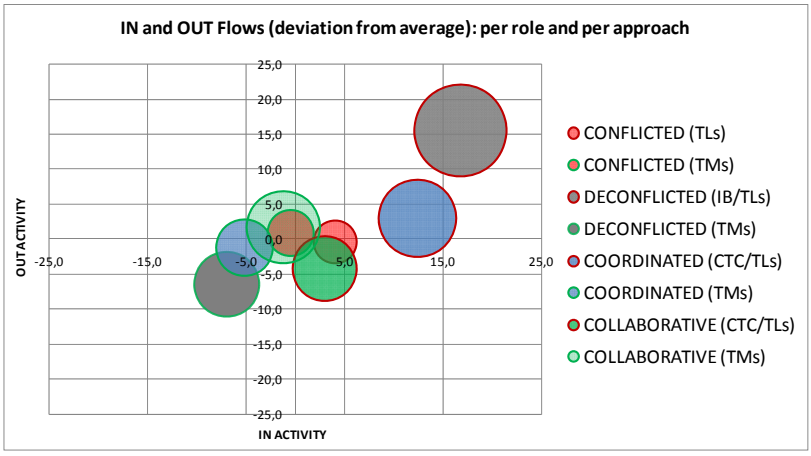
The few number of runs per approach available for analysis is not enough for a robust statistical analysis. Yet, it enables the identification of preliminary results and trends.

Charts displaying mean value in conjunction with maximum and minimum values of the dataset were frequently used. This method provides a visual representation to observe results range and mean trend (towards maximum or minimum).

EXPLANATION OF IN AND OUT FLOWS CHART

The chart center (0 , 0) represents the IN and OUT average per approach. Each node (*bubble)* represents a given role and approach. The more distant a node is from the center it means its behavior is more deviant (from normal). Furthermore, different interpretations are given depending on the value location:

- Nodes located in quadrant 1 (right top part) have propensity for in and out flows (receive and share).
- Nodes located in quadrant 2 (left top part) have propensity for out but not for in flows (not receive and share).
- Nodes located in quadrant 3 (left bottom part) don't have propensity for out nor for in flows (not receive and not share).
- Nodes located in quadrant 4 (right bottom part) have propensity for in but not for out flows (receive and not share).
- Nodes circles diameters are proportional to values' standard deviation.



For clarity:

- Coordinator and leader roles have respective circumference colored in RED
- Team members have respective circumference colored in GREEN.
- Circles areas are colored according to approach as follows: CONFLICTED is RED, DECONFLICTED is GREY, COORDINATED is BLUE, COLLABORATIVE is GREEN.
- EDGE is not applicable (all subjects are assigned as team members). In CONFLICTED, isolated coordinator was excluded from calculations.

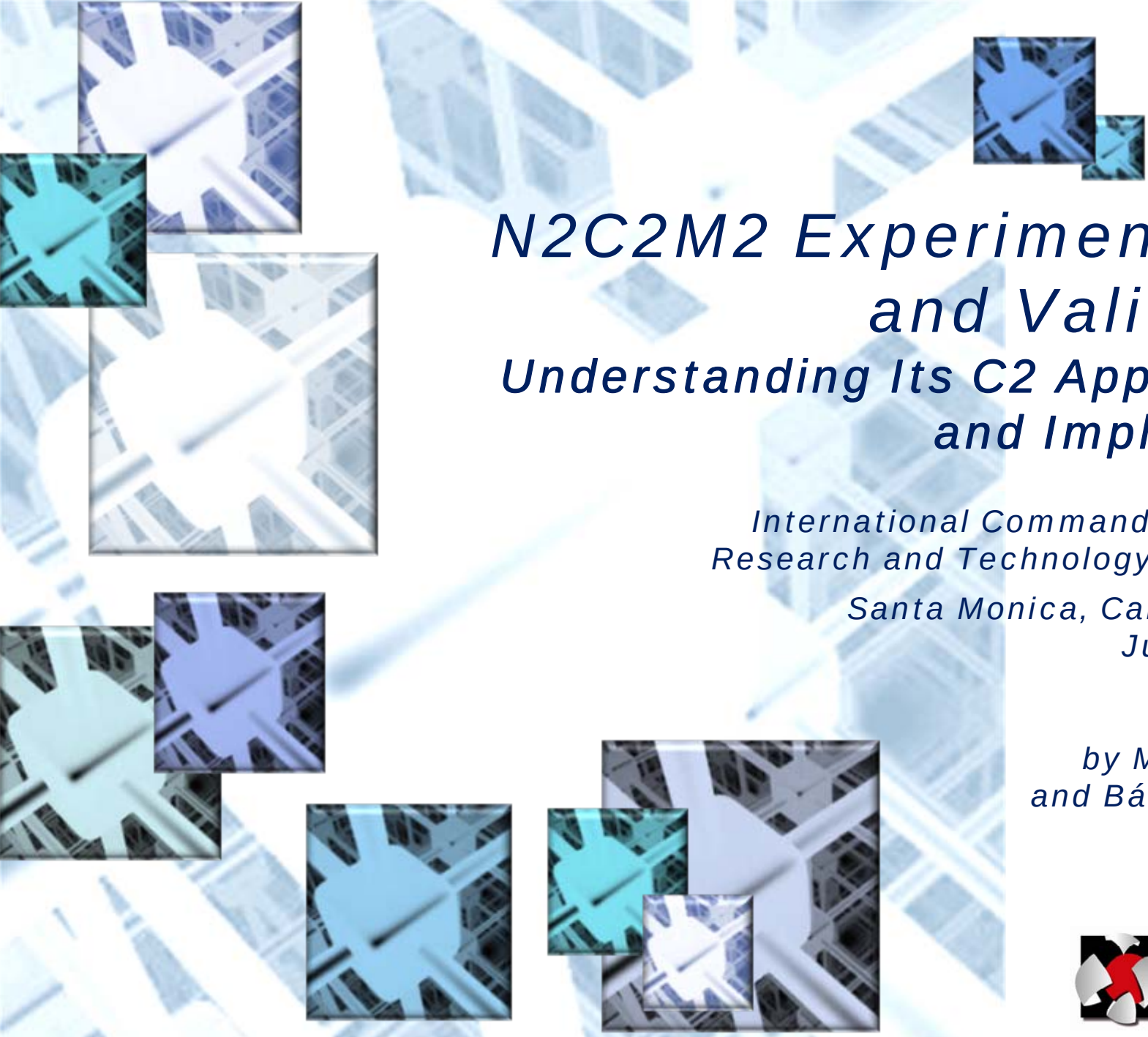
N2C2M2 Experimentation and Validation

Understanding Its C2 Approaches and Implications

International Command and Control Research and Technology Symposium

Santa Monica, California, USA
June 22, 2010

by Marco Manso
and Bárbara Manso



Outline

- **Background**
  - N2C2M2 and theory of NCW
  - ELICIT
- **Experimentation**
  - Early Expectations
  - Model and Key-variables
  - Experiment Design
  - Analysis
- **Conclusions**

Background

N2C2M2 Experimentation

ELICIT Platform

Paper 011
N2C2M2 Experimentation and Validation:
Understanding its C2 Approaches and Implications

Paper 010
Know The Network, Knit The Network:
Applying SNA to N2C2 Maturity Model Experiments

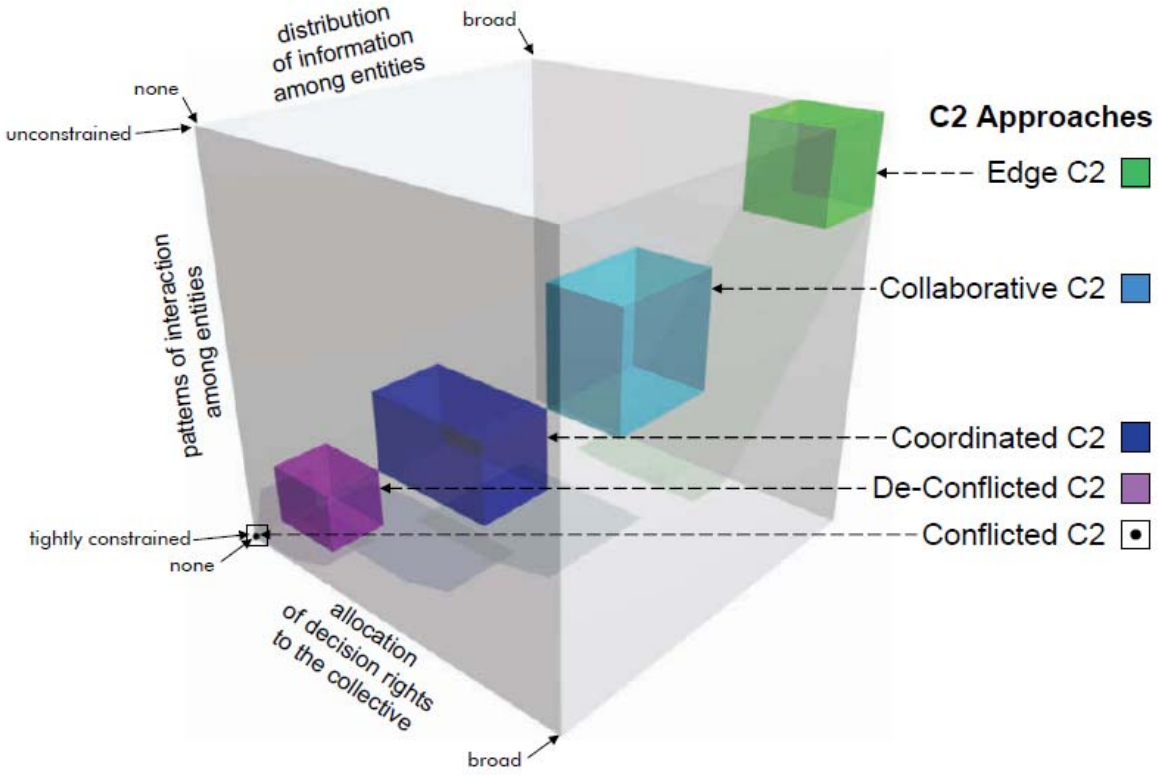
Background

- C2 in the Information Age:
  - Theory of NCW, including *NCW tenets*, *NCW Value Chain* and *C2 Approach Space* (CCRP, Alberts and Hayes)
  - C2 models: C2 CRM (SAS-050)
  - NATO NEC C2 Maturity Model (SAS-065) [1], recently developed and benefiting from multiple validation methods, including experimentation

[1] NATO SAS-065. *NATO NEC C2 Maturity Model*. CCRP Publication Series, 2010.

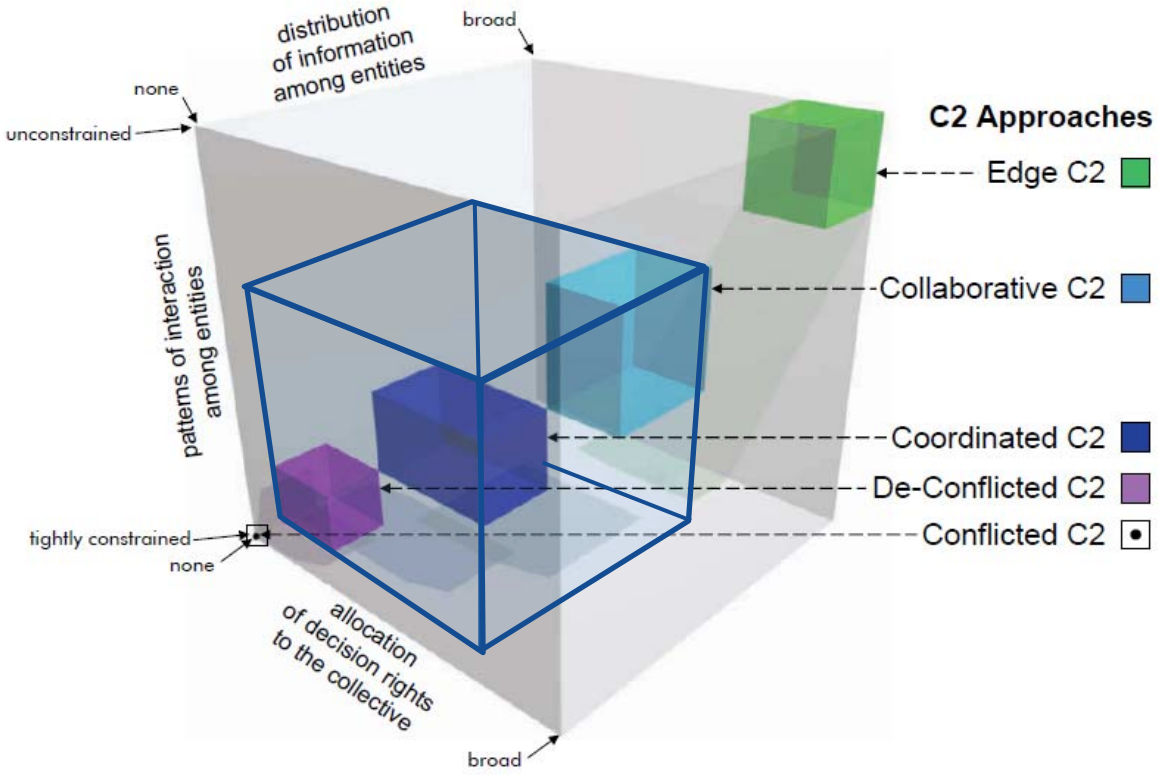
Background: N2C2M2

- NATO NEC C2 Maturity Model
  - Defines 5 levels of NATO NEC operational capability: levels 1 (less mature) to level 5 (more mature).
  - Defines 5 approaches to C2 associated with each level.



Background: N2C2M2

- NATO NEC C2 Maturity Model
  - Defines 5 levels of NATO NEC operational capability: levels 1 (less mature) to level 5 (more mature).
  - Defines 5 approaches to C2 associated with each level.



Level 4 Example

Background: N2C2M2

- NATO NEC C2 Maturity Model (2):
  - More maturity delivers:
    - More effectiveness
    - More efficiency
    - More agility
    - Positive impact in intermediate NCW value-chain variables, such as, *Quality of Individual and Shared Information, Quality of Individual and Shared Awareness and Understanding* and *Self-Synchronization**

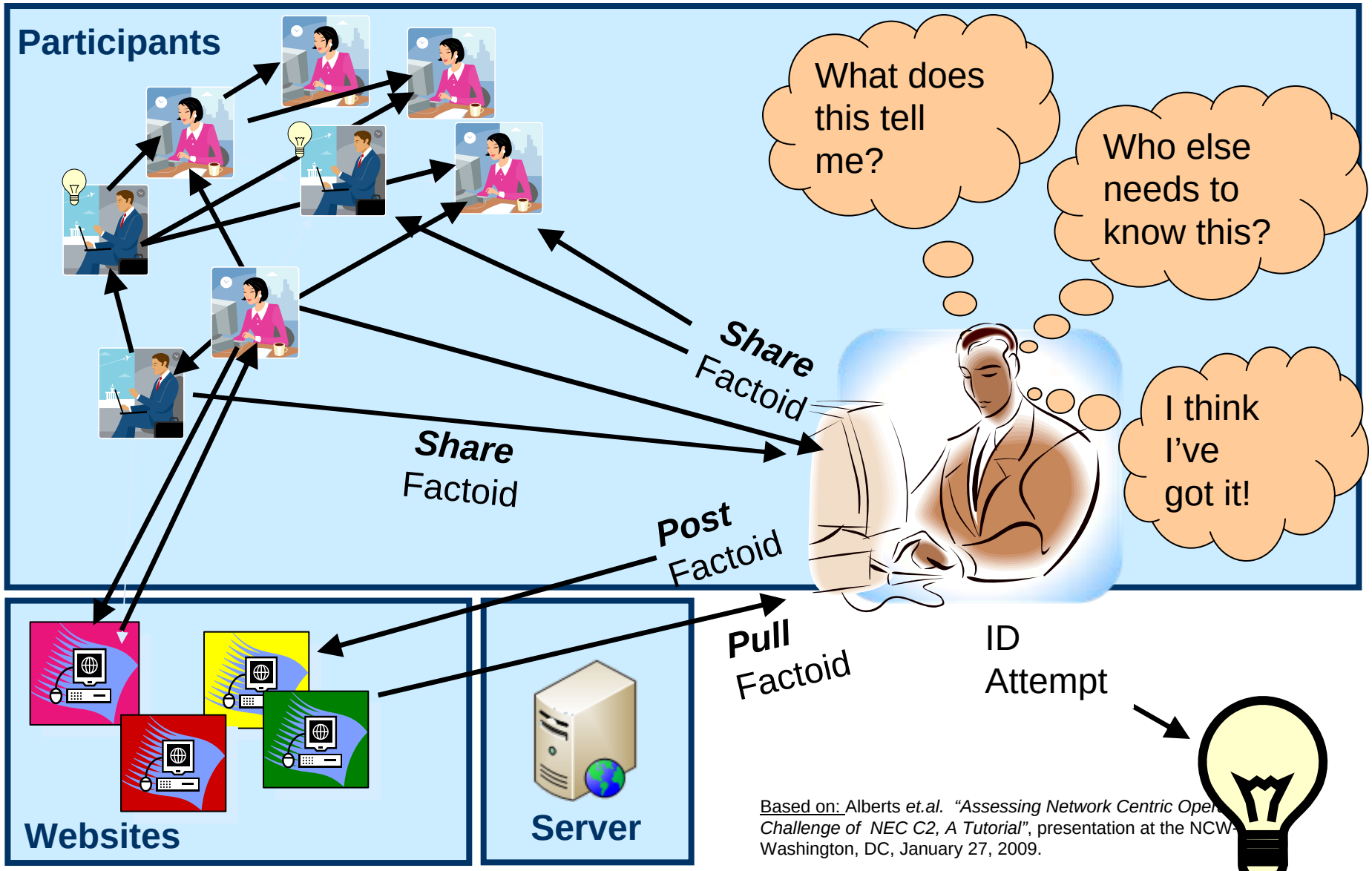
* *For detailed mapping between C2 CRM variables and ELICIT refer to:*
MANSO, Marco, and Paulo NUNES. *ELICIT and the Future C2: Theoretical Foundations for the Analysis of ELICIT Experiments*. Paper presented at the 13th ICCRTS, Seattle, USA, 2008

Background: ELICIT

- ELICIT: **E**xperimental **L**aboratory for the **I**nvestigation of **C**ollaboration, **I**nformation-sharing, and **T**rust.
  - An experimentation environment supported by software tools and instructions/procedures
  - Provides a simple (albeit rich) and collaborative network-centric environment for participating individuals
- Sponsor
  - U.S. DoD Command and Control Research Program (www.dodccrp.org)

Source: Alberts *et.al.* *"Assessing Network Centric Operations The Challenge of NEC C2, A Tutorial"*, presentation at the NCW-2009, Washington, DC, January 27, 2009.

Background: ELICIT



Based on: Alberts *et.al.* *"Assessing Network Centric Oper… Challenge of NEC C2, A Tutorial"*, presentation at the NCW… Washington, DC, January 27, 2009.

Experimentation: Early Expectations

Main hypotheses for validation:

- [1] For a complex endeavor , higher collective C2 maturity approaches are **more effective**.
- [2] For a given level of effectiveness, higher collective C2 maturity approaches are **more efficient**.
- [3] Higher collective C2 maturity approaches are **more agile**.

Experimentation: Early Expectations

Additional hypotheses:

- Higher collective C2 maturity approaches exhibit increased/better levels of:

  [4] Quality of Individual and Shared Information;

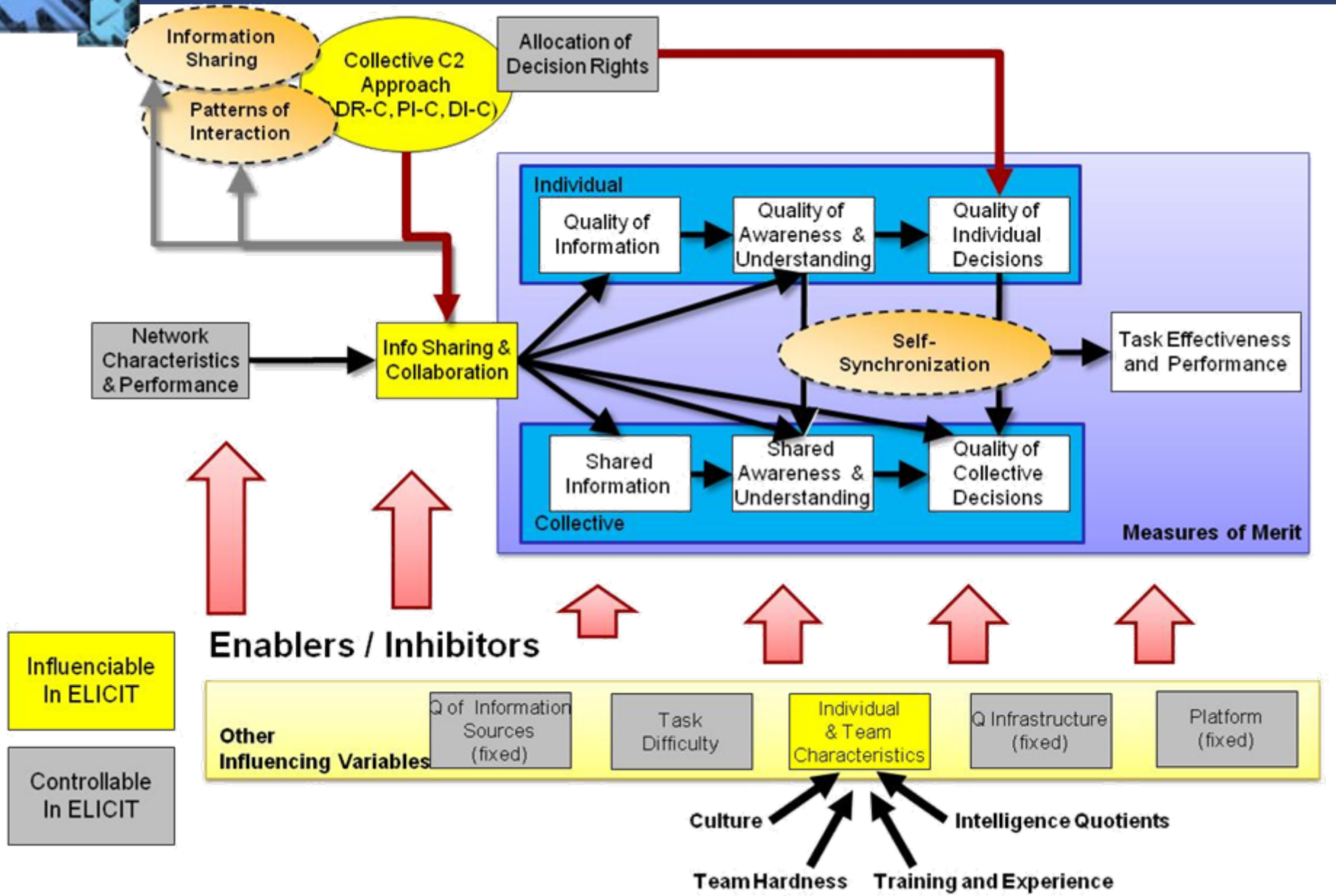
  [5] Quality of Individual and Shared Awareness and Understanding;

  [6] Self-Synchronization (at cognitive level);

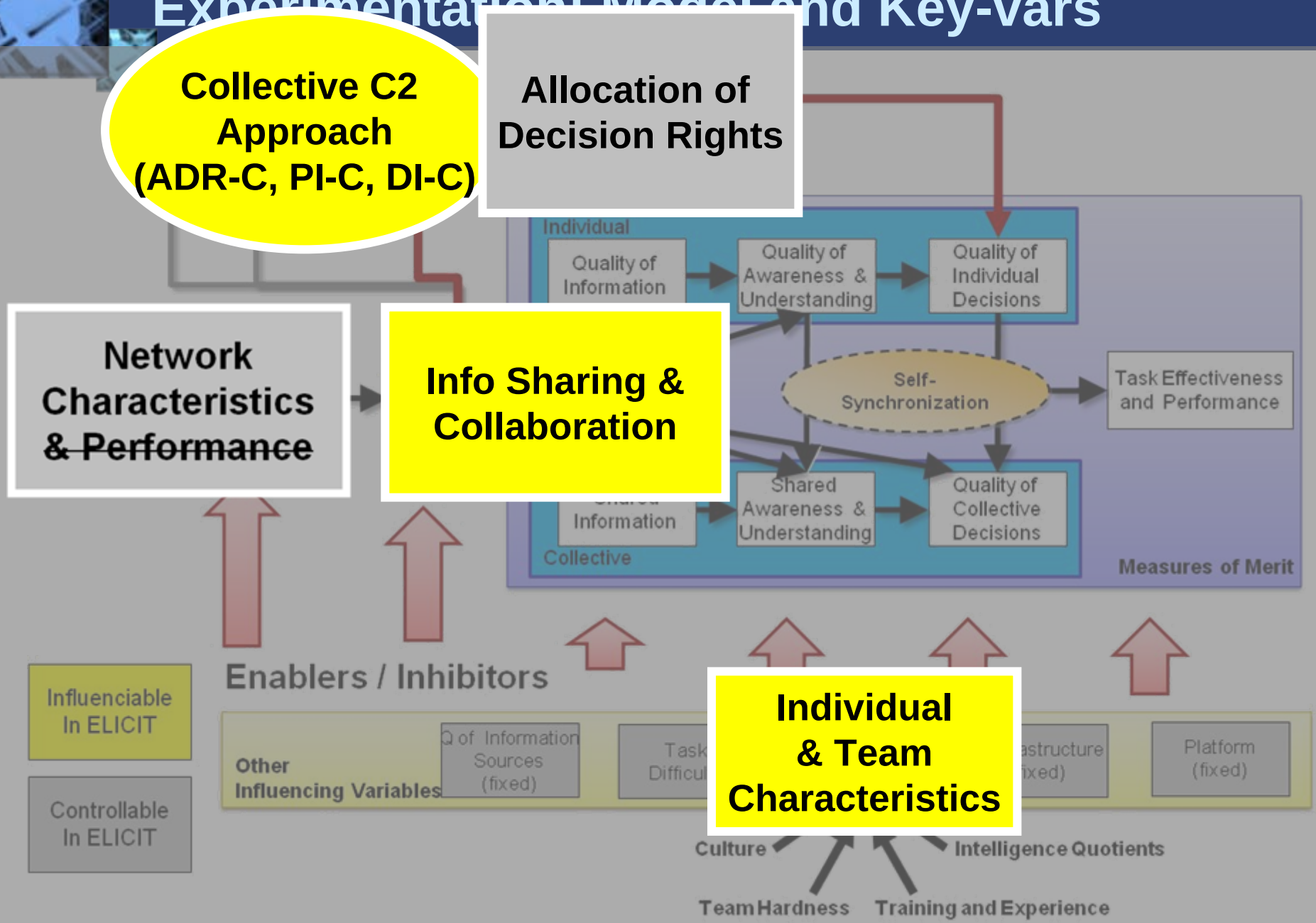
  Than: lower collective C2 maturity approaches.

- [7] Organizations require a minimum level of maturity to be effective in ELICIT.
- [8] Increasing the degree of difficulty in ELICIT require organizations to increase their level of maturity to maintain effectiveness in ELICIT.

Experimentation: Model and Key-vars



Experimentation: Model and Key-vars



Experimentation: Manipulations

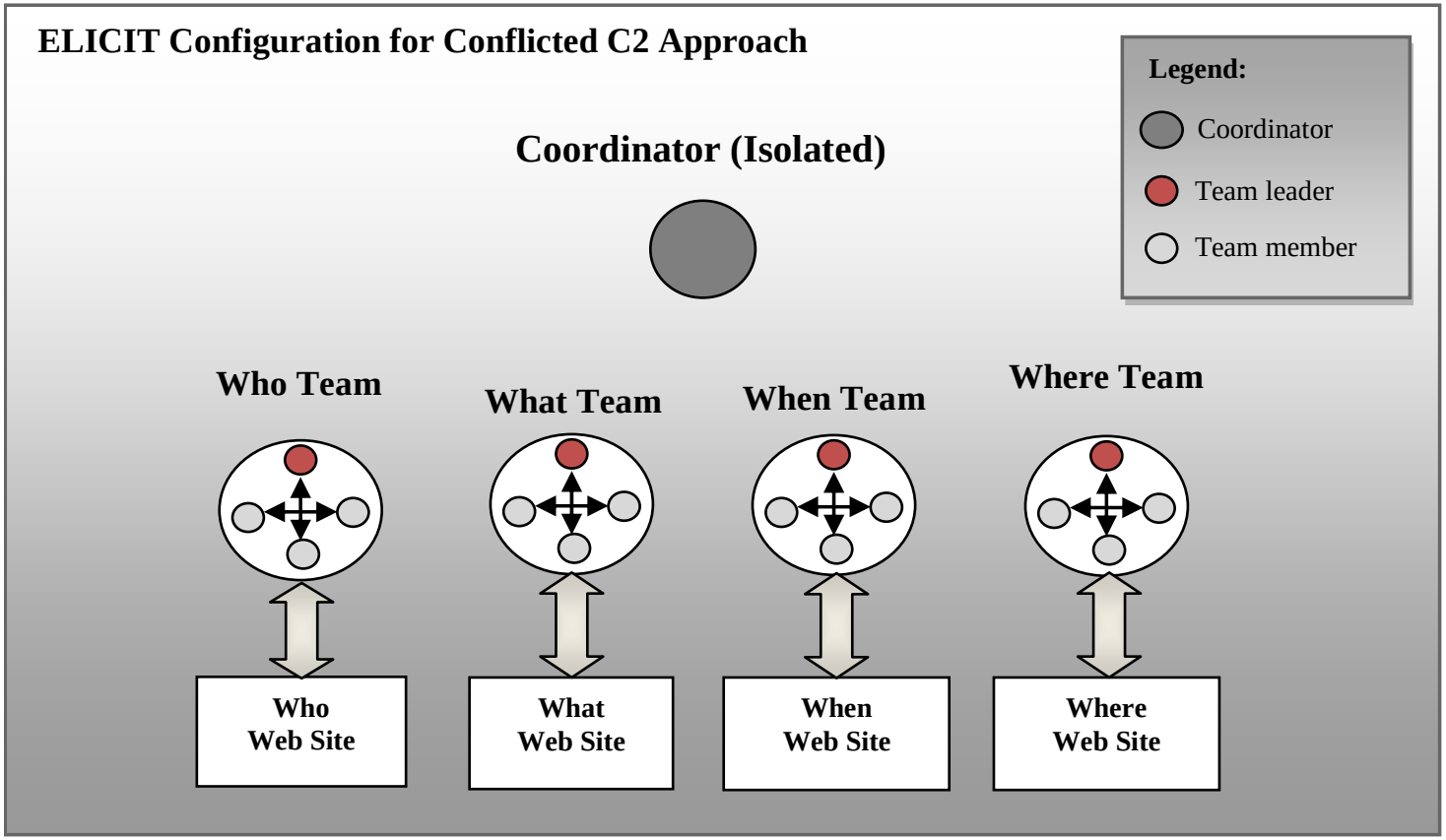
Name	Description
Network Characteristics and Performance	Allow or restrict interactions between: - subjects and teams. - subjects and websites. **This variable affects PI-C and DI-C**.
Information Sharing and (incentives for) Collaboration	Control: predefined server distributions of all factoids to subjects (in three waves). Influence: distribution of information as a result of human sharing and posting (human *will*) We will attempt to induce / influence collaborative behavior by: - defining collective or isolated goals - set individual and collective decision rights (see **ADR**) See paper for further notes on *Individual and Team Characteristics*. **This variable affects PI-C and DI-C**.
Allocation of Decision Rights	Decision rights will be allocated according to the C2 Approach to implement: - Distributed for higher maturity approaches; - None / (de)centralized for lower maturity approaches. **This variable is a C2 dimension**.

Experimentation: Design

Common aspects for all approaches:

- **Entities**: 4 TEAMS and 1 SINGLE ENTITY, except EDGE with 17 ENTITIES
- **Context**: complex endeavor with two or more force elements (entities) present with overlapping intents; operating in the same 'space' and time; and, an entity actions may conflict with those taken by another entities." (Alberts and Hayes 2007).
- **Scenario**: future terrorist attack
- **Task**: identify the "who", "what", "where" and "when" of the attack within a specific timeframe.
- **Information Sharing Capabilities**: *share*, *post* and *pull* actions. High maturity approaches will be enriched with more options (see next).
- **Collaborative Capabilities**: ability to provide "assessment" of importance (relevance) and/or trustworthiness of a factoid.
- **Resource Contention**: subject hoarding of relevant information is considered as a conflict. Cognitive efforts are required.

Experimentation: CONFLICTED model

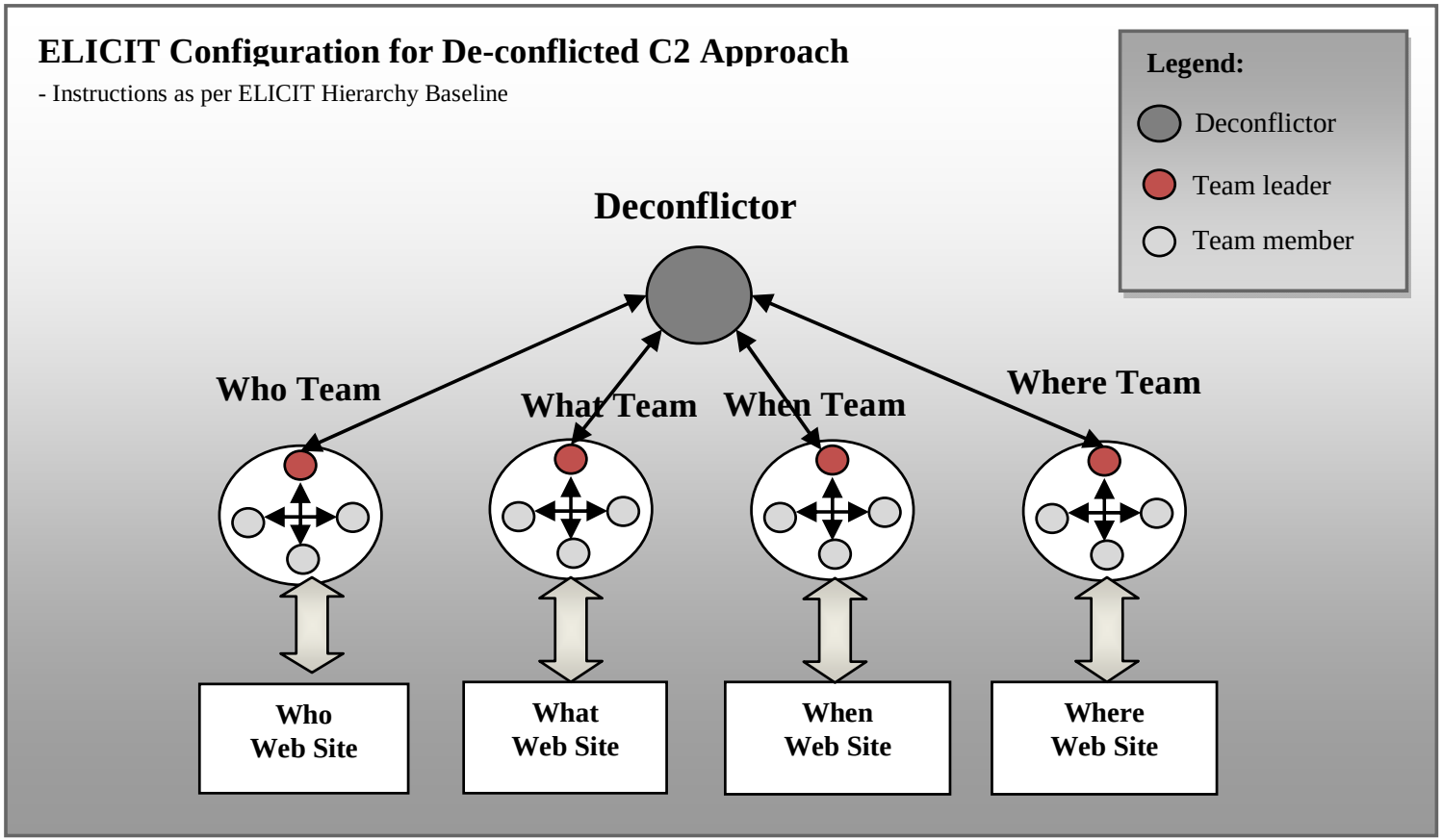


SUCESS CRITERION

Each Team pursues independent goals.

Success occurs if each Team leader finds the correct solution to his problem space.

Experimentation: DE-CONFLICTED model

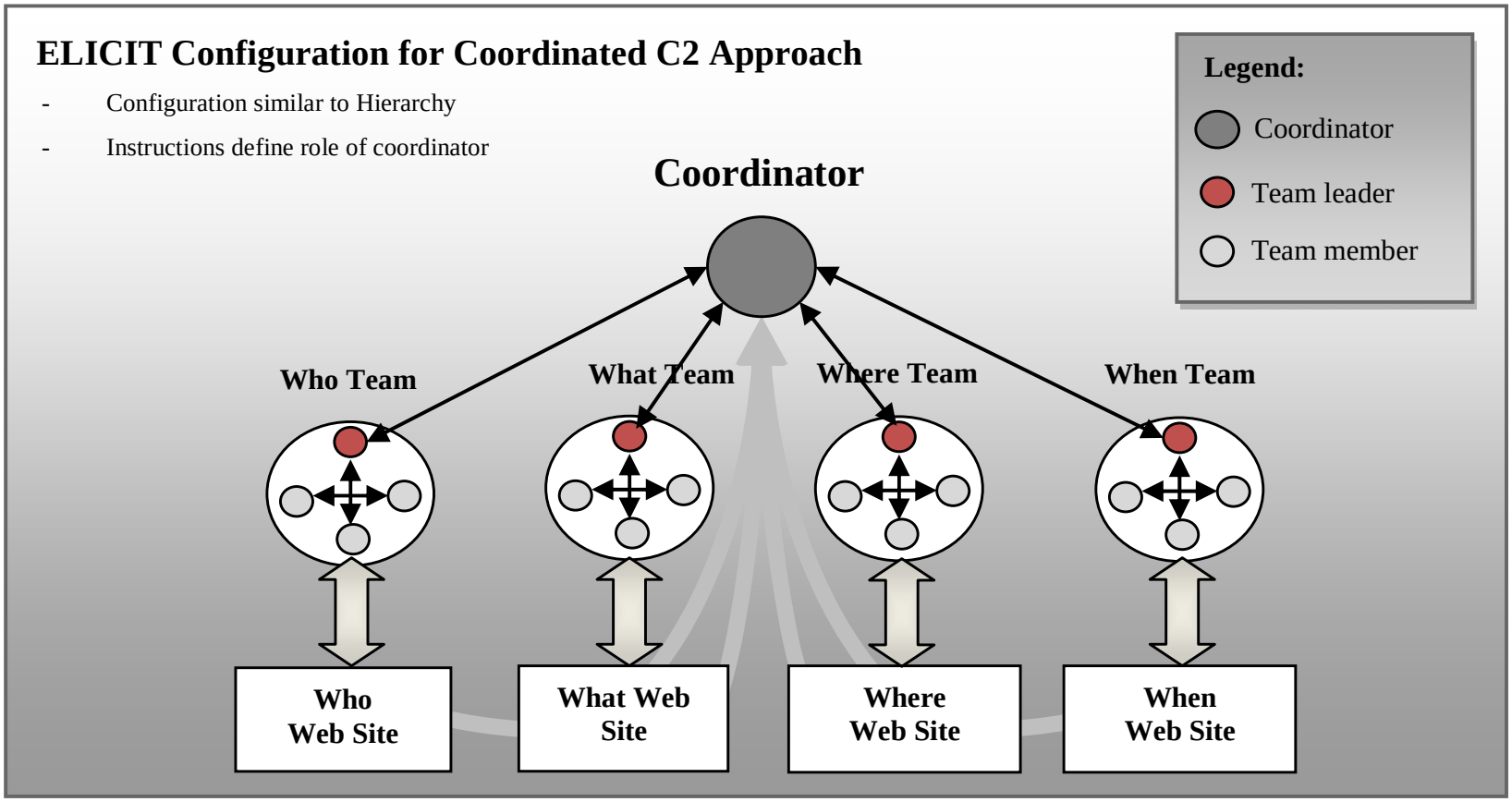


SUCESS CRITERION

Each Team pursues independent goals.

Success occurs if each Team leader finds the correct solution to his problem space.

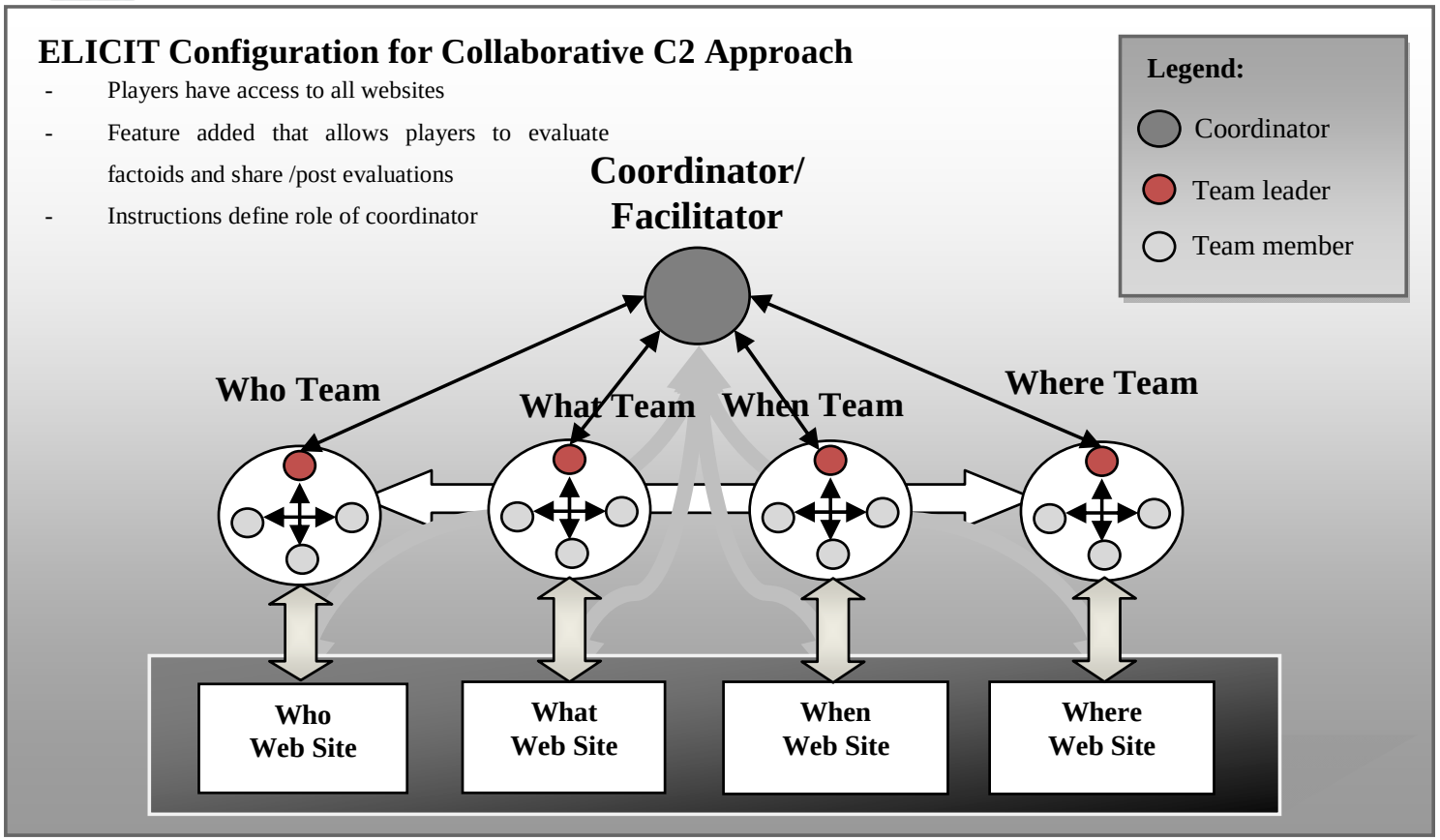
Experimentation: COORDINATED model



SUCESS CRITERION

Organization success depends on the Coordinator finding the correct solution.

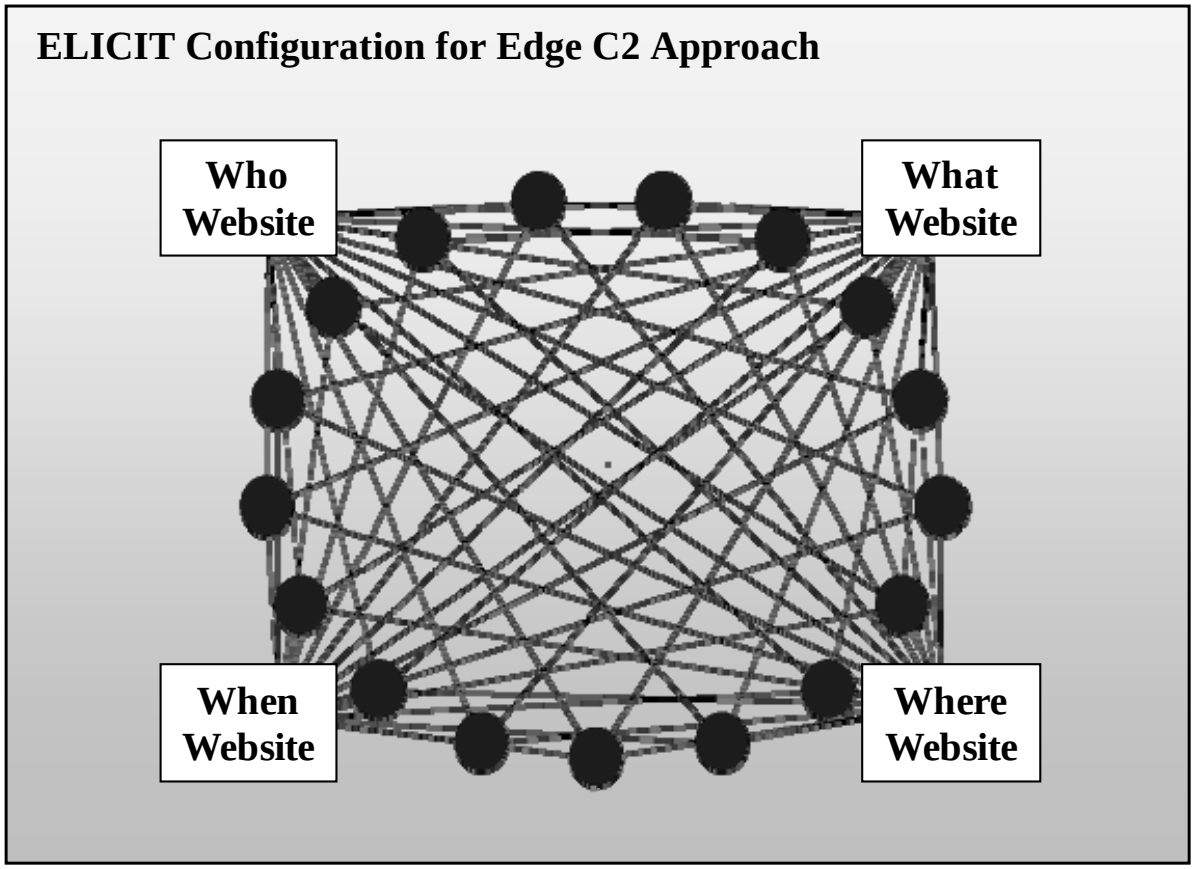
Experimentation: COLLABORATIVE model



SUCESS CRITERION

Coordinator finding the correct solution to all problem spaces OR Team leaders finding the correct solution to their problem space.

Experimentation: EDGE model



SUCESS CRITERION

Organization success depends on the individuals' IDs plurality being correct in each problem space.

Analysis: Experiments Baseline

18 valid runs performed with human subjects:

- 3 runs for CONFLICTED
- 4 runs for DE-CONFLICTED
- 4 runs for COORDINATED
- 4 runs for COLLABORATIVE
- 3 runs for EDGE

Usually, a group of 17 subjects was used to perform two runs. A *test* run (15 to 30 min) was always conducted prior to first *real* run.

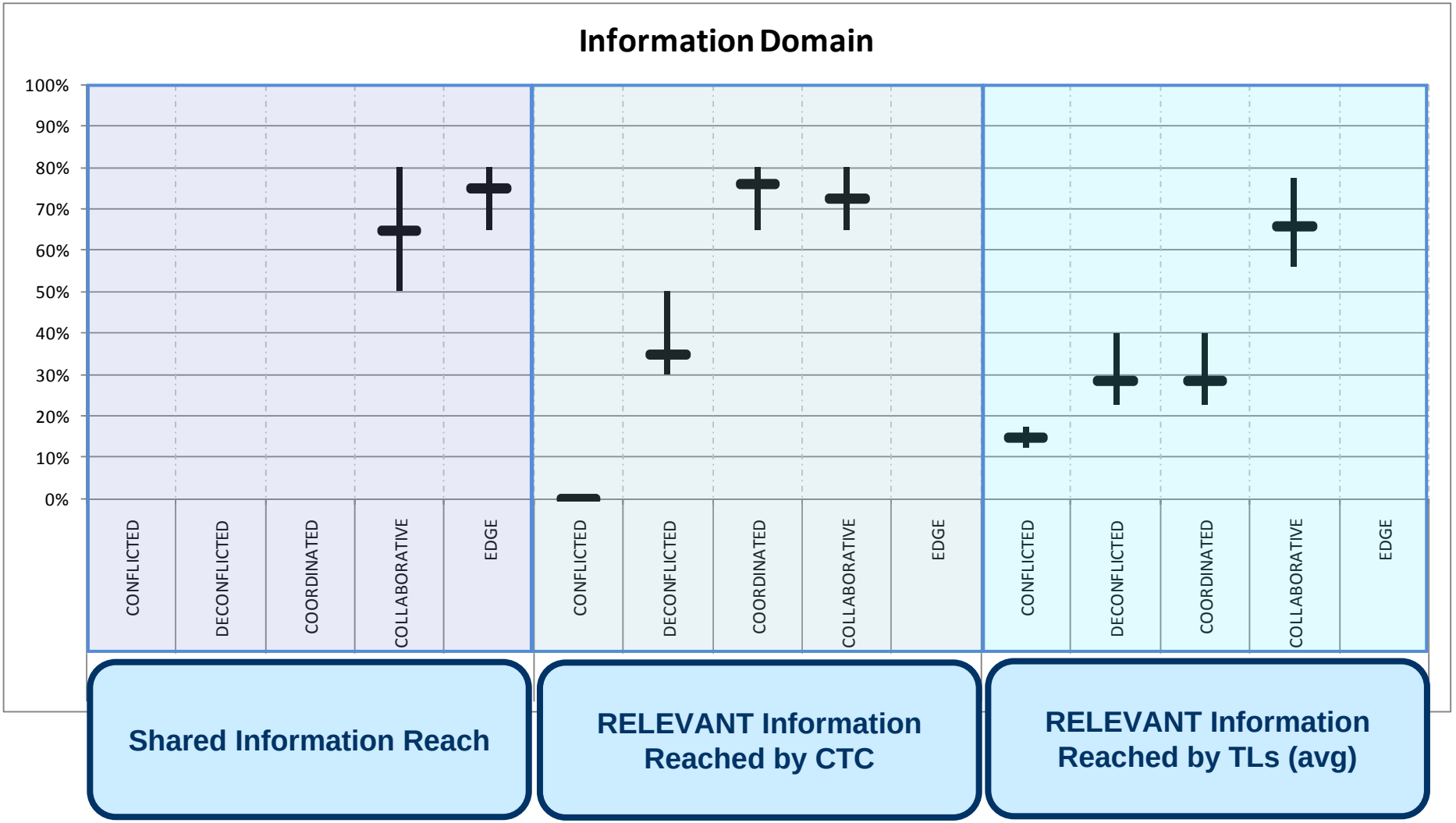
This means:

- About 150 military cadets participated in ELICIT runs.
- About 10 hours of data to analyze
- 9 979 actions, comprising:
  2 290 shares, 1 880 posts, 4 979 pulls and 712 IDs
- Software Analysis Tool: more than 50K SLOC

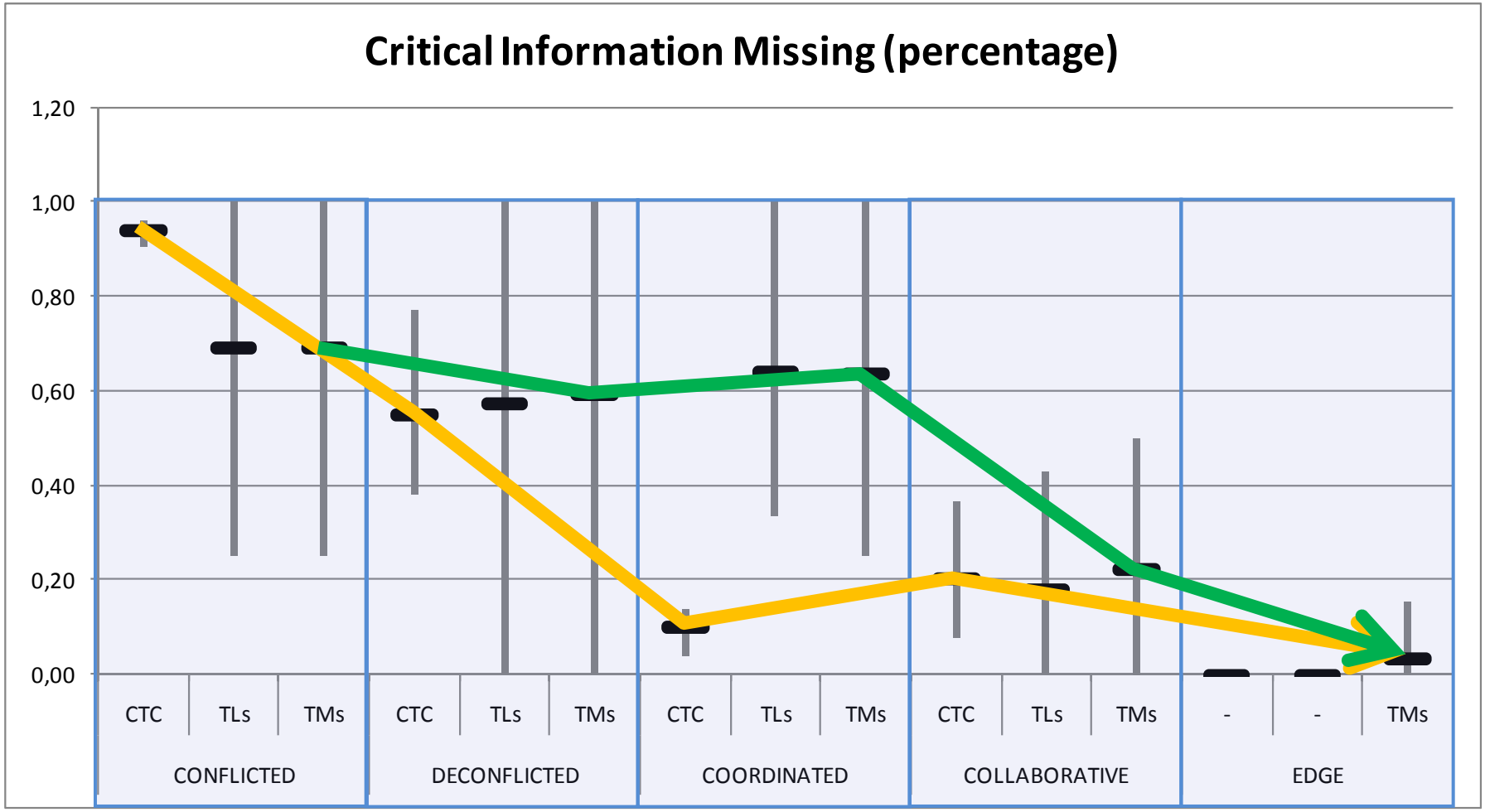
Analysis: Overview

- Information Domain
- Interactions and Social Domain
- Cognitive Domain
- Measures of Merit

Analysis: Information Domain



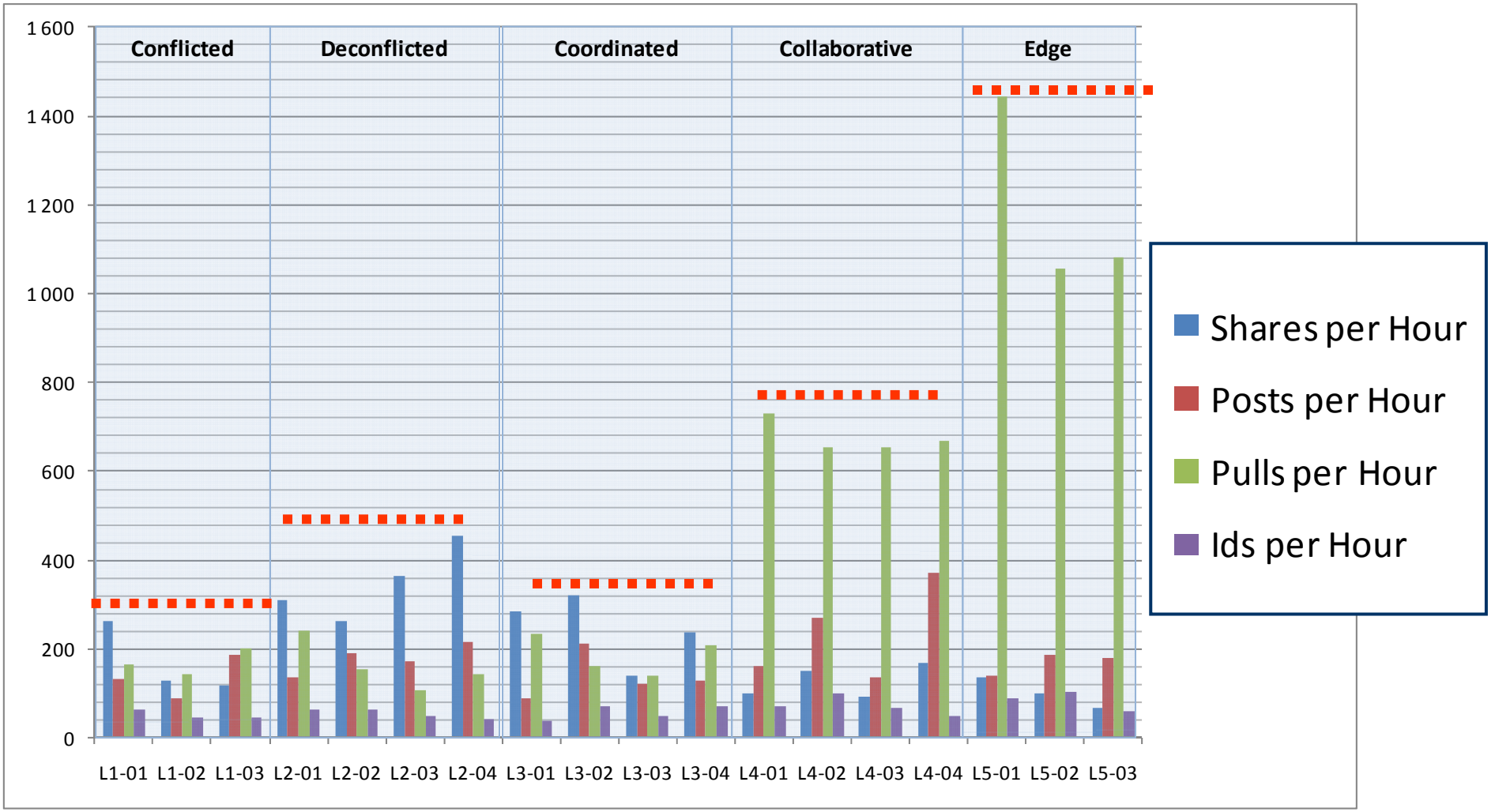
Analysis: Information Domain



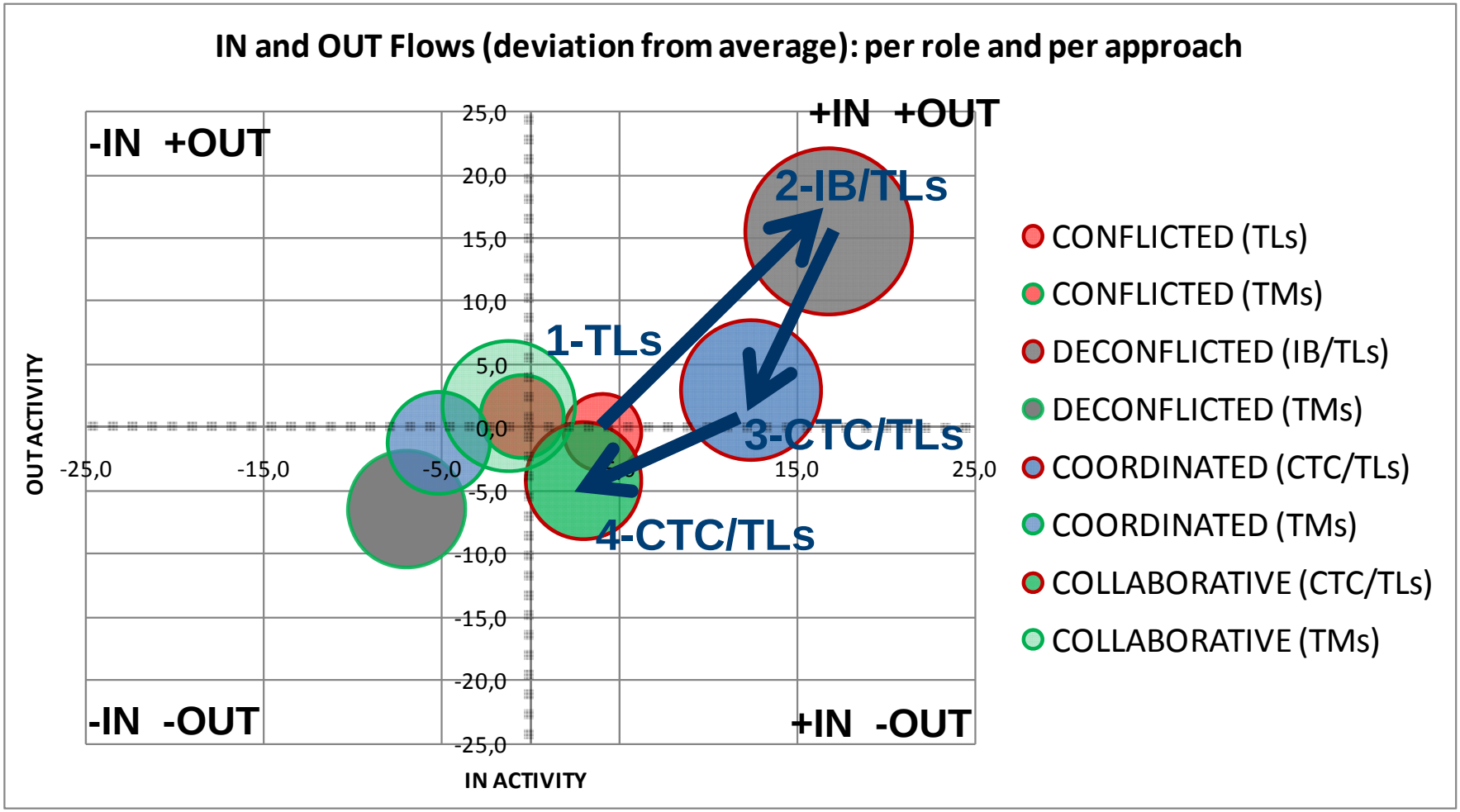
CTC TMs

Analysis: Interactions and Social Domain

Nature and quantity of Interactions:



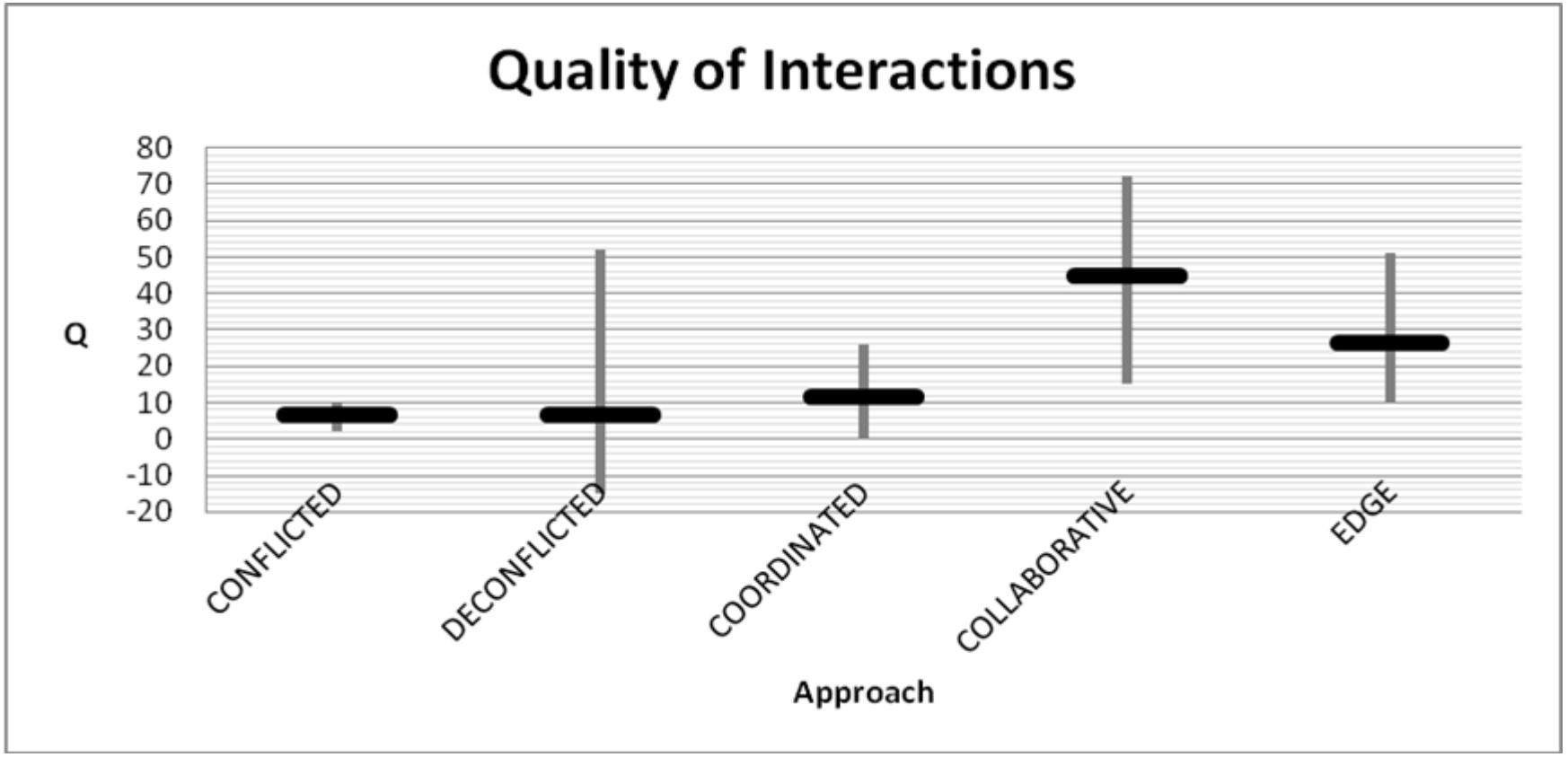
Analysis: Interactions and Social Domain



$$IN\_DEV_{S_i} = (nbr\_shares\_received_{S_i} + nbr\_pulls_{S_i}) - (Average\_nbr\_shares\_received + Average\_nbr\_pulls)$$

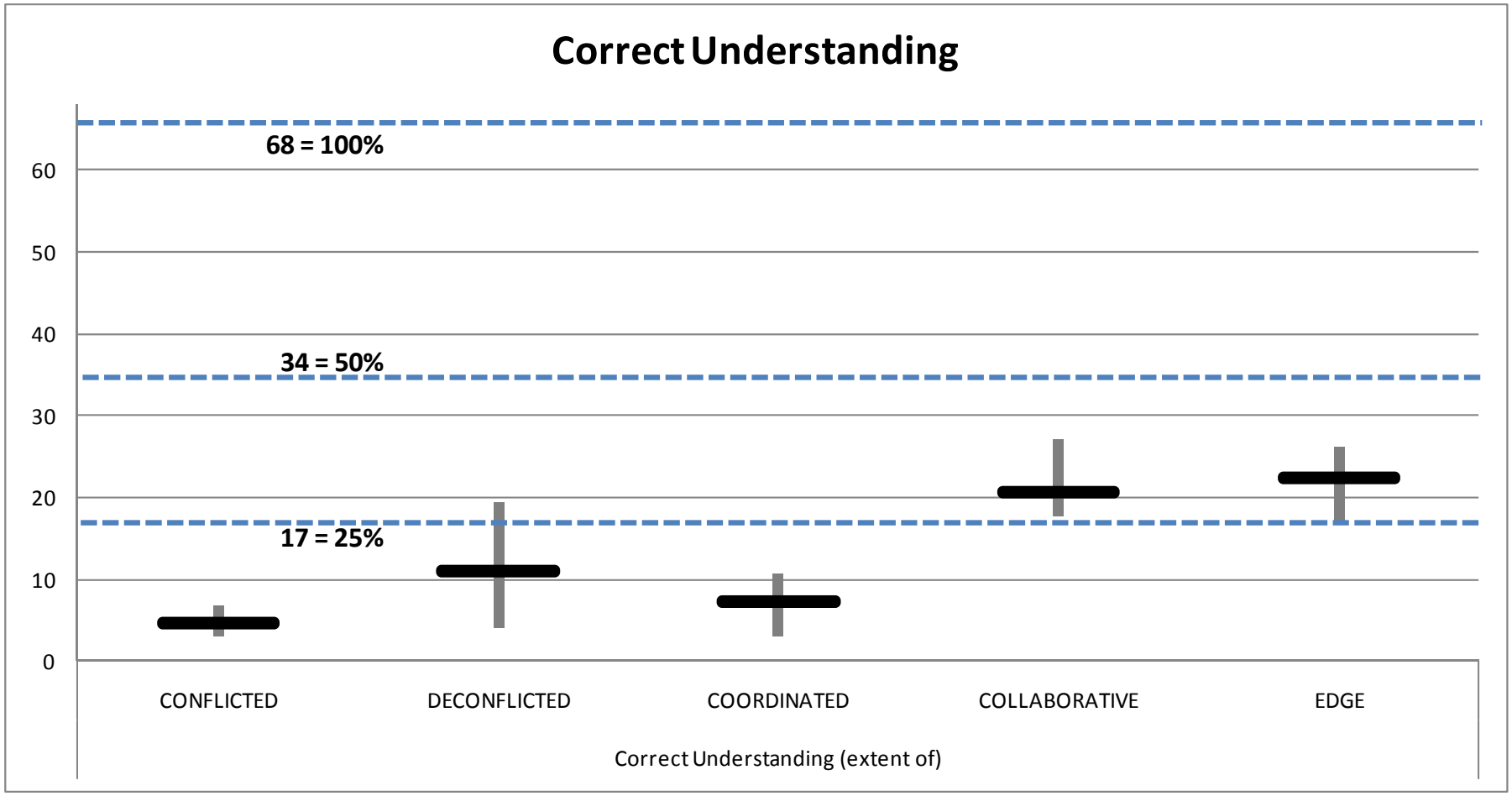
$$OUT\_DEV_{S_i} = (nbr\_shares\_sent_{S_i} + nbr\_posts_{S_i}) - (Average\_nbr\_shares\_sent + Average\_nbr\_posts)$$

Analysis: Interactions and Social Domain

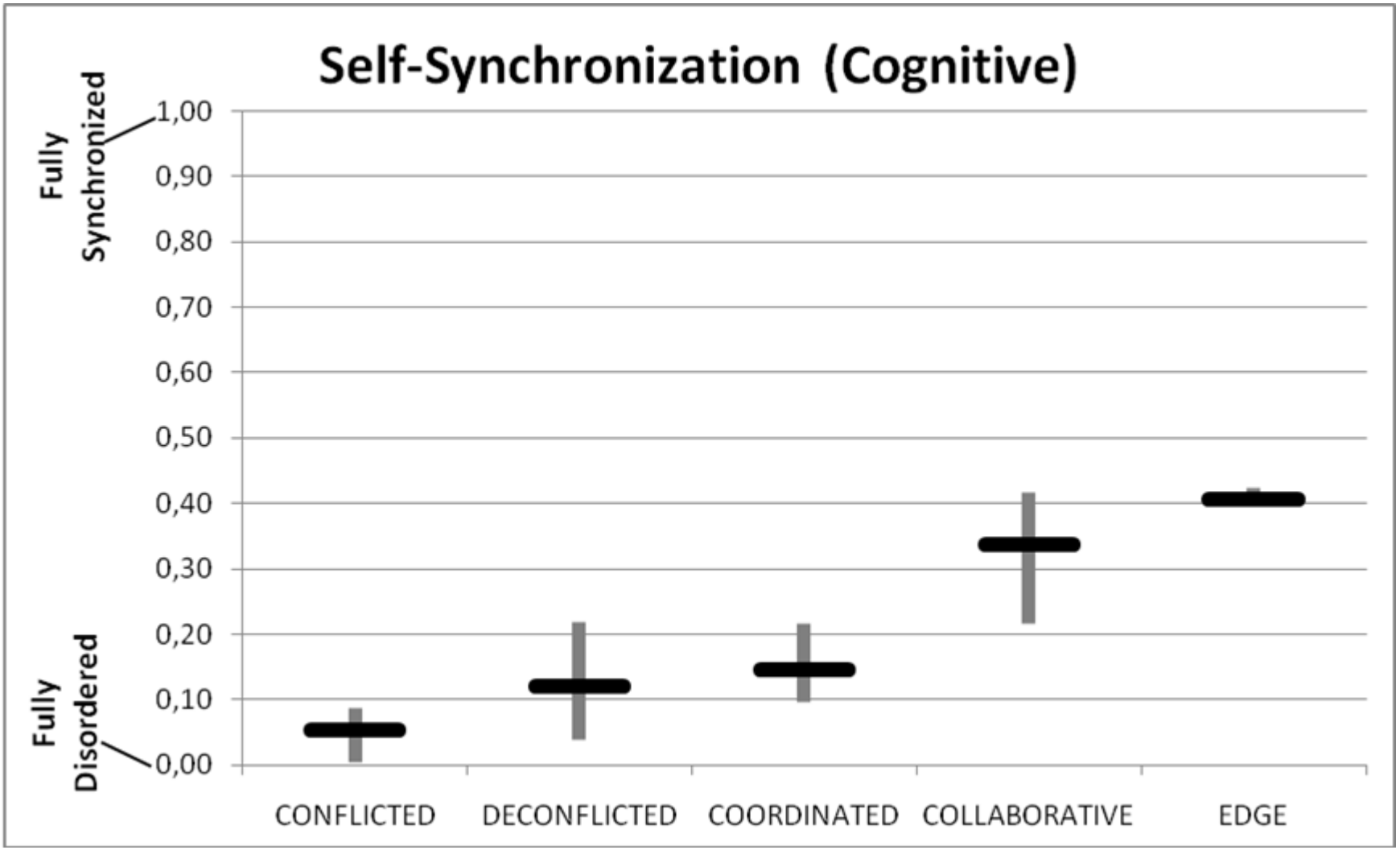


$$Q_{Interactions} = \sum R\_factoids_{shared\_and\_posted} - \sum N\_factoids_{shared\_and\_posted}$$

Analysis: Cognitive Domain

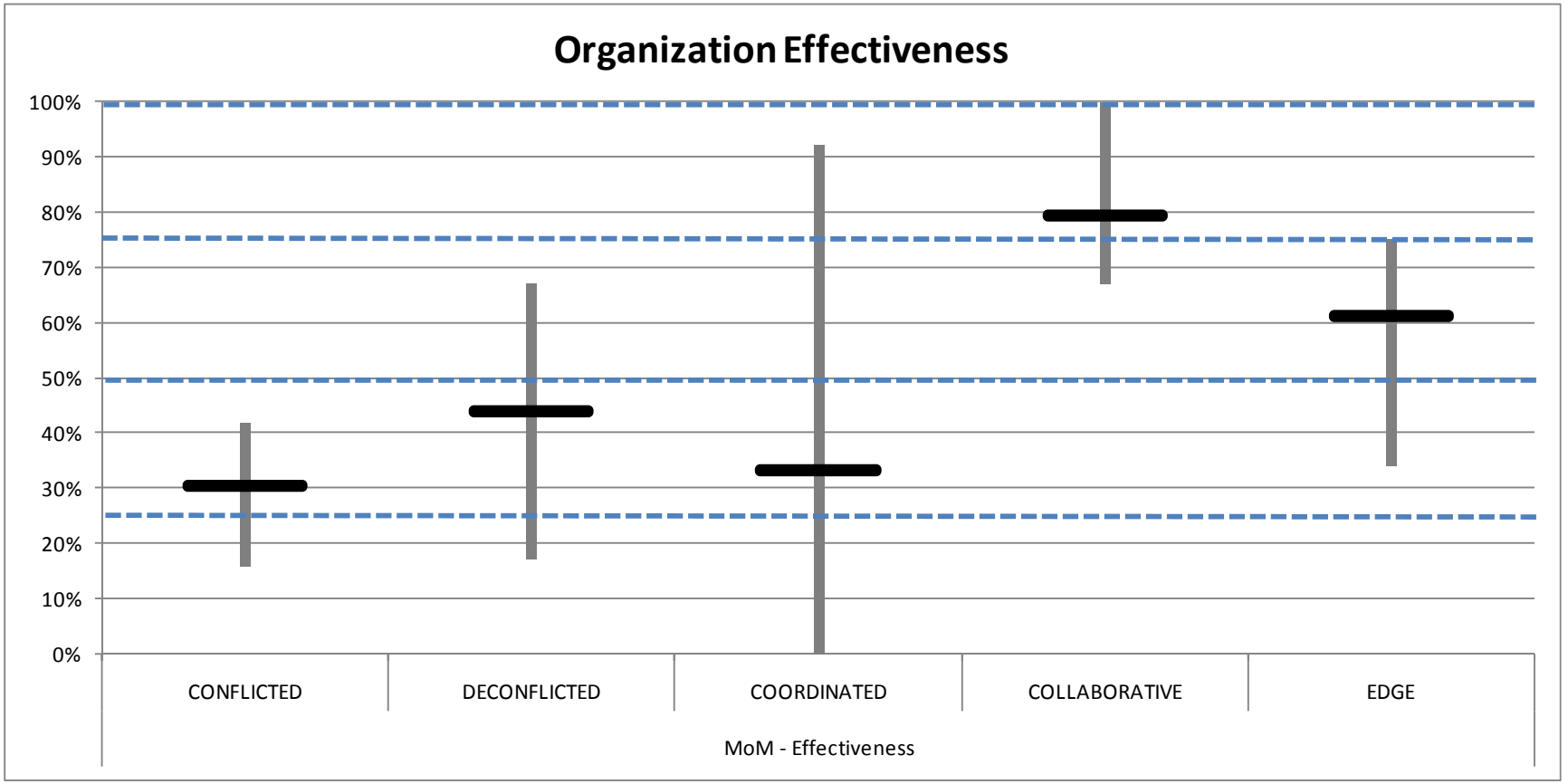


Analysis: Cognitive Domain



$$\text{CSSync}_{problemSpace} = 1 - \sum_{i=1}^{N} P(S_i) * \ln(P(S_i)) / Max\_Disorder_{problemSpace}$$

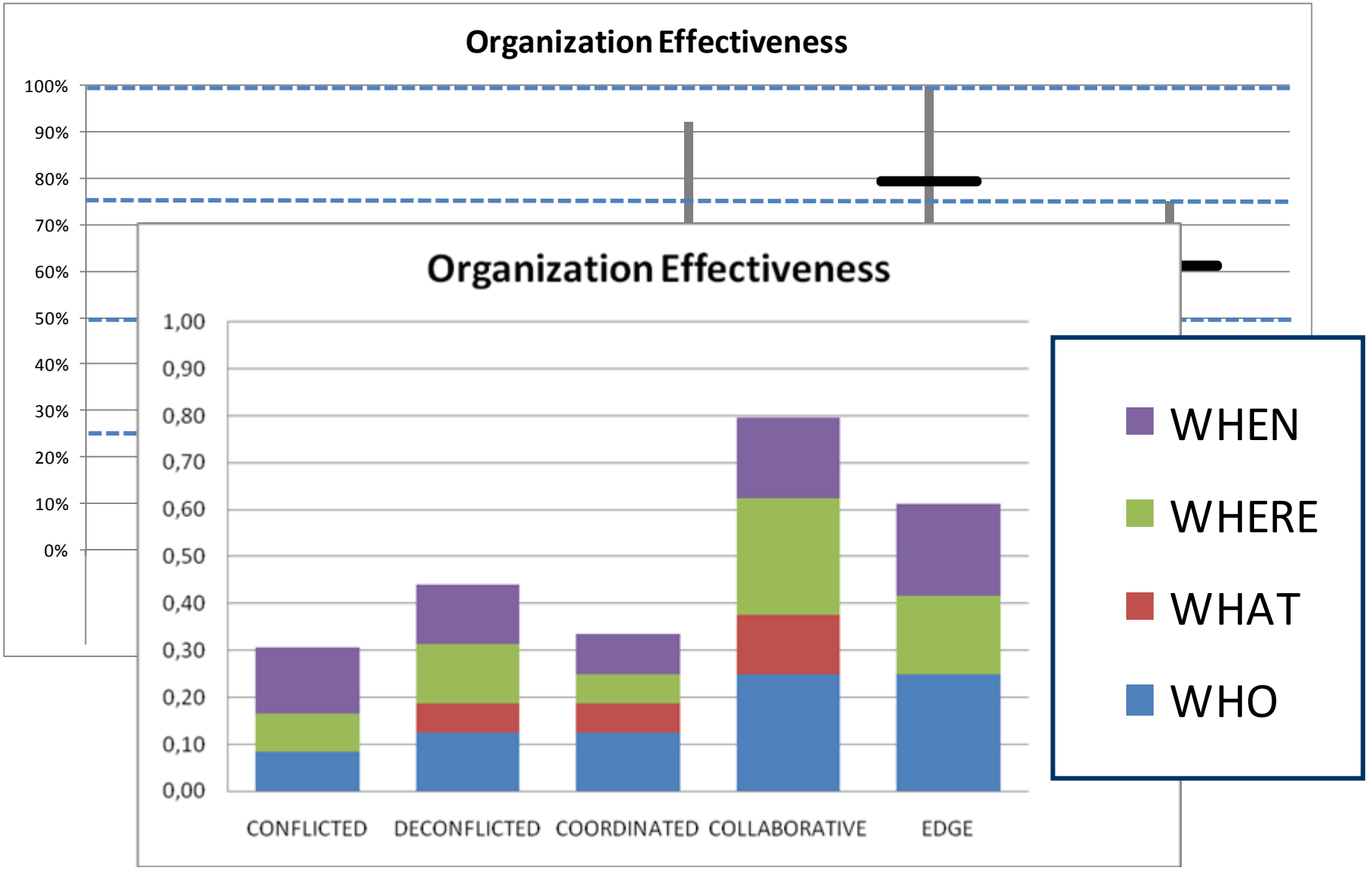
Analysis: MoM



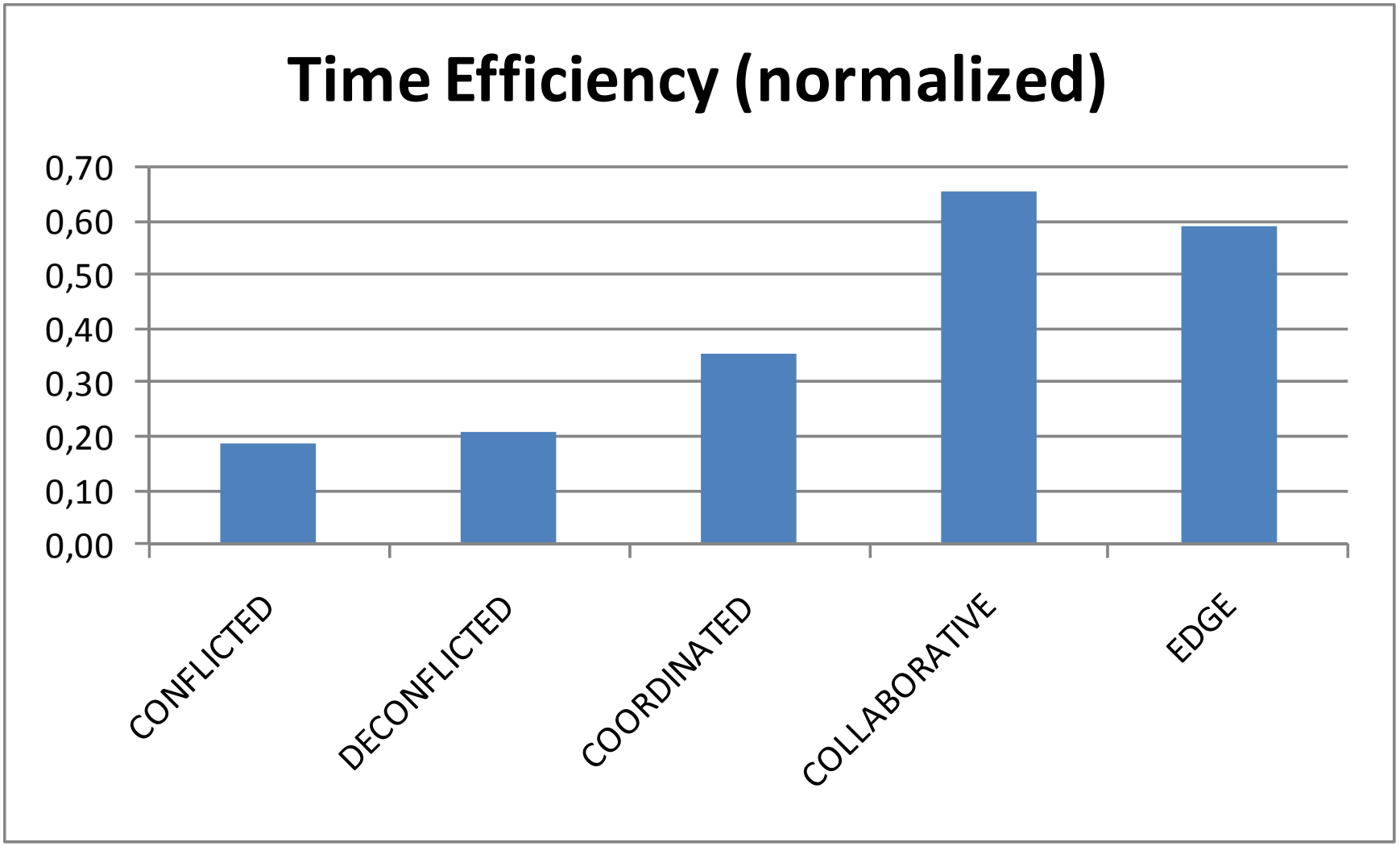
$$Effectiveness = \sum_{i} 0.25 * Correct\_ans_i$$

$Correct\_ans_i$ is 1.0 if correct answer is provided and 0.0 otherwise

Analysis: MoM

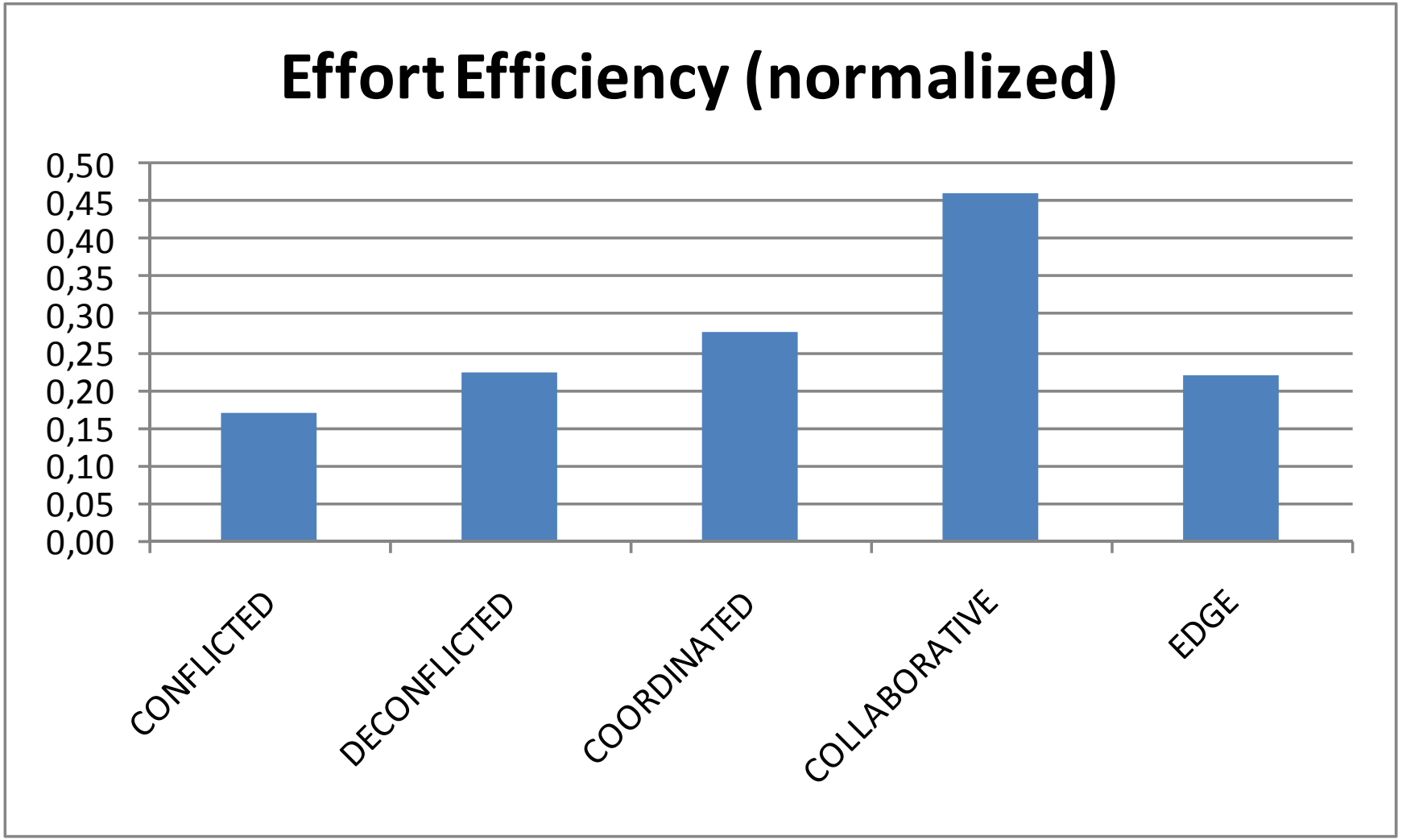


Analysis: MoM



$$Efficiency_{time} = Effectiveness\_score^2 * \log_{10}(1 + 1/time\_last\_ID)$$

Analysis: MoM



$$Efficiency_{effort} = Effectiveness\_score^2 * \log_{10}(1 + {}^{1}\!/_{effort\_spent})$$

Conclusions

Domain / Variable Assessed \ C2 Approach		CONFLICTED	DECONFLICTED	COORDINATED	COLLABORATIVE	EDGE
Information Domain	Shared Information Reach	5	4	3	2	1
	Critical Information Accessible	5	4	3	2	1
Interactions	Quality of Interactions	5	4	3	1	2
Cognitive Domain	Extent of Correct Understanding	5	3	4	2	1
	Cognitive Self-Synchronization	5	4	3	2	1
MoM	Organization Effectiveness	5	3	4	1	2
	Time-Efficiency	5	4	3	1	2
	Effort-Efficiency	5	3	2	1	3

Conclusions

Results are consistent with model expectations (in overall):

[4] *Higher collective C2 maturity approaches exhibit increased/better levels of **Quality of Individual and Shared Information** than lower collective C2 maturity approaches.*

- **OK**

[5] *Higher collective C2 maturity approaches exhibit increased/better levels of **Quality of Individual and Shared Awareness and Understanding** than lower collective C2 maturity approaches.*

- **OK – except for Coordinated**

[6] *Higher collective C2 maturity approaches exhibit increased/better levels of **Self-Synchronization (at cognitive level)** than lower collective C2 maturity approaches.*

- **OK**

Conclusions

Results are consistent with model expectations (in overall):

[1] *For a complex endeavor, higher collective C2 maturity approaches are more effective.*

- **OK – except for EDGE**

[2] *For a given level of effectiveness, higher collective C2 maturity approaches are more efficient.*

- **OK – except for EDGE (with a high-deviation)**

[3] *Higher collective C2 maturity approaches are more agile.*

NOT Covered

Agile C2 is a novel concept under the analysis of SAS-085. This hypothesis will be considered in future research work.

Conclusions

Results are consistent with model expectations (in overall):

[7] *Organizations require a minimum level of maturity to be effective in ELICIT.*

Considering current dataset, requisite maturity in ELICIT is COLLABORATIVE or COORDINATED (having a proper CTC).

[8] *Increasing the degree of difficulty in ELICIT require organizations to increase their level of maturity to maintain effectiveness in ELICIT.*

NOT Covered

There is no sufficient data (factoid set 2 trials) to test this hypothesis.

..:: Thank You for Your Attention ::..

Questions?